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Mo AND U MINERALIZATION WITH SPECIAL REFERENCE TO A Mo-(U) DEPOSIT AT CARMI, B.C.

by

© JOHN MICHAEL KENYON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Mo And U Mineralization With Special Reference to a Mo-(U) Deposit at Carmi, B.C.

submitted by John Michael Kenyon

in partial fulfilment of the requirements for the degree of Master of Science.

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Date January 31, 1978.

ABSTRACT

The geology and nature of the Carmi Mo-(U) deposit, situated in the Omineca Crystalline Belt, south central British Columbia, are documented. In addition, the geochemistry of Mo and U are discussed throughout a range of geological environments. In igneous environments, both Mo and U are preferentially enriched in late-stage fractions of differentiating magmas. The two elements are commonly zoned, with U being deposited in lower temperature environments.

At Carmi, rocks ranging in age from Precambrian to Tertiary are exposed but only the Jurassic Nelson batholith and the Cretaceous Valhalla intrusion are discussed. The Nelson batholith is represented by a foliated epidote-biotite-granodiorite whilst the Valhalla suite is represented by a massive muscovite-biotite- quartz monzonite. Both intrusions are believed to be differentiates of a common magmatic suite. The Valhalla quartz monzonite underlies the Nelson member at Carmi and does not crop out.

Two mineralized breccia bodies have been discovered to date (namely the "E" and "Lake" zones) and are localized within the Nelson unit. Molybdenite occurs in angular fragments of Nelson granodiorite and within the quartz-rich breccia matrices. Brannerite is restricted to the quartz matrix of the "E" zone.

Porphyry-type hydrothermal alteration is largely confined to the mineralized zones. Pervasive propylitic alteration, in part a result of regional metamorphism, occurs outside the breccia zones.

Quartz-sericite alteration affects all parts of the breccias. A small portion of the "E" zone breccia has been affected by potassic alteration.

Since the breccia fragments show no milling effects, the breccia zones are proposed to have been generated by the collapse of the Nelson granodiorite into vapor-rich voids formed at the Nelson-Valhalla interface. Such vapor voids might form from exsolved water released during the injection of the Valhalla quartz monzonite magma. Fluids from the Valhalla permeated the breccias producing the coeval porphyry-type hydrothermal alteration, Mo and U mineralization and the quartz cement.

The present proven combined tonnage and grade of the breccia zones is 34.5 million tonnes (38 million tons) of 0.151% MoS_2. Although the U content is sporadic, intersected brannerite mineralization averages approximately 1.0 lb/ton U_3O_8. The Carmi deposit must be considered one of the major undeveloped Mo porphyry deposits in Western Canada today.

In this area, the search for further reserves and new exploration targets is best directed by soil geochemistry. Geophysical methods have met with limited success.

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CHAPTER 1

INTRODUCTION

This study deals with the diadochic relationship of Mo and U with special reference to a Mo-(U) deposit at Carmi, southern British Columbia. The genetic and geochemical association of Mo and U are considered and the petrology, mineralogy and genesis of the Carmi deposit described. Information and data presented are compiled in part from published literature and partly from detailed study of the Carmi deposit. Some 85 thin sections were studied for petrologic and mineralogic interpretations, 4 polished sections for opaque-mineral characteristics and 110 rock slabs were stained for feldspar modal analyses to classify the major rock variants. Dating of the mineralizing event (from a brannerite crystal separate) was kindly carried out by Dr. H. Baadsgaard with the help of G. Bloy. Gamma-ray spectrometric analyses of the major rock variants were performed with the aim of defining the probable origin of the U and hence the Mo mineralization.

Location and Access

The Carmi Mo-(U) deposit is located in south central British Columbia along the western margin of the Nelson Batholith at 49° 31' N latitude and 119° 10' W longitude, in the Greenwood Mining Division. The property lies 3 miles north west of the hamlet of Carmi, a near-deserted mining town established in the early 1900's and 50 miles south

of the city of Kelowna. Carmi is easily accessable from Kelowna via Highway 33. The mining town of Beaverdell is 5 miles south of Carmi and serves as the supply point for exploration in the area. An abandoned spur of the C.P.R. line passes through Carmi to Kelowna and Penticton. Access to the area is provided by a network of logging and forestry access roads, few of which require 4-wheel drive vehicles.

Physiography

The study area comprises part of a slightly undulating plateau region bounded on all sides by deeply cut valleys. Relief on the plateau rises to 4500 feet (1365 m) from a base elevation of 2000 feet (605 m) in the West Kettle River valley. Slopes are quite steep and incised with short narrow draws, occupied by intermittent streams during the spring. Swamps or bogs are few and there is only one small permanent lake on the property.

The climate is similar to the Okanagan valley area to the west but the Carmi sector receives more precipitation. Consequently, the hill-sides are well-forested and covered by a variety of evergreens at higher elevations and by some deciduous trees in the valley bottoms. Much of the area was burned at some point in the past and where original growths were destroyed, a dense secondary growth occurs. Logging operations have been carried out in the past, and some of the plateau is still held under tree farm licenses.

Mining History of the District

The Highland Bell Ag-Pb-Zn mine at Beaverdell is presently the only producing mineral deposit in the district. It has been in continuous operation since 1901. Numerous other Ag-Pb bearing vein occurrences

are known and a precious metals-bearing shear zone was mined intermittently at Carmi during the 1920's and 1930's.

Since this period, intermittent interest has been aroused with various vein or replacement mineralization in roof pendants, but it was not until 1960 that a renewed interest in disseminated mineralization within the intrusives was aroused.

CHAPTER 2

Mo-U MELT GEOCHEMISTRY

The elements molybdenum and uranium display similar crystal chemistry as outlined below in Table 1.

TABLE 1

Mo, U ELEMENT PROPERTIES

	MOLYBDENUM	URANIUM
valence states*	+2 - +6	+3 - +6
electronegativity	1.8	1.7
atomic radius (Å)	1.39	1.38
ionic radius (Å)	0.70(+4), 0.62(+6)	0.97(+4), 0.80(+6)
acid/base prop.	acidic	amphoteric

*Mo^{+6} and U^{+6} are the most common and stable

For atomic substitutions it is the size of the atomic and ionic radii that is the governing factor. It has been found that at room temperature, elements may substitute if their ionic radii do not differ by more than 15%. Higher temperatures permit a greater tolerance

(Mason 1966). However, there will be no substitutions if the difference in atomic charge of the ions is greater than one, even if the sizes are appropriate, due largely to the difficulty in balancing charge requirements by substitution in other parts of a mineral formula (ibid).

With Mo and U, in the +4 valency states, the ions have too great a size discrepancy in radii to substitute in diadochy with the common rock-forming elements. The +6 valency states, while still being over the 15% substitution value, may interchange at high temperatures. The acid/base properties of the two elements show that U is capable of acting either as an acid or base and that Mo is acidic. The two properties of ionic radii suitability and acid/base affinity are the most important in the melt geochemical behavior of Mo and U. These two properties govern the net residual concentration of the two elements in the late-stage hydrothermal fluids.

Environments of Deposition

Studies of Mo-U ore deposits shows that they span the complete range of geologic environments; i.e., from sedimentary-hosted (low temperature) Colorado Plateau uraniferous deposits to hydrothermal and metamorphic (medium temperature) vein and replacement deposits, to disseminated igneous porphyry deposits (high temperature).

Data from the analyses of uraniferous Colorado Plateau sedimentary deposits have shown that U and Mo are transported in groundwater regimes as neutral to alkaline solutions (pH 7 to 8.5) in association with some or all of the following anions: $(OH)^-$, F^-, CO_3^{-2}, SO_4^{-2}, $P_2O_7^{-4}$, and Cl^- (Buntebarth 1976, Granger and Warren 1969). It is believed that the U and Mo were transported as carbonate complexes or by solutions rich in

CO_2 at temperatures below 30°C (Fischer 1970).

Metamorphic and hydrothermal U-Mo vein deposits have been studied in the U.S.S.R. and mention has been made of locales in Canada and the U.S.A. Temperatures of deposition in the U-Mo hydrothermal vein deposits range from 150°C to 300°C (Barsukov et al. 1971, Mel'nikov and Berzina 1973, Roedder 1971).

For igneous disseminated U-Mo deposits, the temperatures of deposition appear to range between 400°C and 800°C (Roedder 1971, Mackie 1977). The mode of deposition is by hydrothermal fluids derived from granitic emplacement (ibid). No pH conditions for either medium or high temperature deposits have been determined.

It is clear that Mo and U in igneous environments are associated with hydrothermal events. It has been further determined by Bohse et al. (1974) that Mo and U show a common geochemical behavior in that they are commonly enriched in late-stage, felsic, silicic and potassic members of comagmatic igneous suites. Within an intrusion, the border phases are normally enriched in Mo and U relative to the central phase and the elements have clearly migrated towards the geochemical barrier presented by the wallrock--intrusion interface (Buntebarth 1976).

Theoretical Studies

The melt geochemistry of Mo and U has been determined by a number of authors. Rekharskiy (1971) states that the principal structural units of acid and intermediate melts are aluminosilicates. Due to the strong polarizing effect of silicon upon oxygen, covalent bonds are formed. Ions of U^{+4} and Mo^{+4} have bond energies close to those of silicon and oxygen and thus may enter into silicate structures. Mo^{+6} and U^{+6} however,

do not have physical properties compatible with silicon-oxygen nor with aluminosilicate structures and are thus expelled from crystallizing melts.

Isuk (1976) has shown that Mo exhibits a remarkably high solubility in hydrous sodium disilicate liquids in the system $Na_2Si_2O_5$ - $MoS_2 \cdot H_2O$. He proposed that the system is analagous in many respects to subalkalic melt compositions. The solubility of MoS_2 increased with increasing temperature up to 650°C after which it began to decrease. Conversely, cooling of the melt would expell MoS_2. Isuk's (1976) observations clearly complement Rekharskiy's (1971) earlier experiments.

By analogy with Colorado Plateau uraniferous deposits it has been assumed that igneous-hosted Mo and U were transported as carbonate complexes or by solutions rich in CO_2 (Ruzicka 1971, Tugarinov et al. 1973, Barsukov et al. 1971). The fact that carbonate complexes probably do <u>not</u> play a large transport role in igneous systems is perhaps substantiated by the paucity of carbonate minerals in the igneous occurrences.

Whole-rock analyses of Mo and U igneous hosts, show a high concentration of alkalic metals and halides (Rekharskiy 1971). Within a melt, the alkali metals have the greatest mobility. During dissociation of water, the alkali metal cations become associated with hydroxide and in this state they move freely within the silicate melt. Mo^{+6} and U^{+6} ions unite with acids formed from F^- and Cl^- and with the alkai metal hydroxides. This gives the Mo and U ions greater mobility and thus crystallization and differentiation of the magma causes them to be concentrated within residual fluids. U^{+6} has greater mobility than does Mo^{+6} and so is more likely to be concentrated in the very late-stage residual fluids and melts (Rekharskiy 1971, Bohse et al. 1974).

Alternative transport theories for igneous occurrences have been

offered by Tugarinov et al. (1973) and by Fleischer (1959). Tugarinov et al. (1973) believed that both Mo and U might be transported simultaneously as hexavalent uranyl molybdate complexes in the presence of F, Ca, and H_2S and that they are reduced to the quadrivalent state upon deposition. Bohse (1974) and Fleischer (1959) point to the transport of Mo and U in the hexavalent state as MoO_3F^- and UF_6. The fact that F and Cl play a major part in the transport mechanism is substantiated by the ubiquitious presence of fluorite with Mo-U deposits and by the occurrence of sylvite and halite as daughter crystals in fluid inclusions as studied by Roedder (1971) in deposits where Mo and U occur together. Kilinc (1972) has found that even at 8 kbars of pressure, the chloride molality in the aqueous phase of a crystallizing magma is about 10 times that within the melt. He believes that experimental evidence indicates that base-and precious-metals are strongly partitioned toward the chloride-rich solutions. It should be noted that studies of Mo and U transport mechanisms have indicated the association of tungsten and beryllium with chloride and fluoride complexes which would suggest that in addition to Mo and U, W and Be display similar affinities (Rekharskiy 1971).

Precipitation of Mo and U are determined by the presence of constituents that will aid pH changes, reduction, adsorption, ion exchange, or cause the formation of insoluble complexes. The chief agents for sedimentary U-Mo deposition appear to be carbonaceous matter, bacteriogenic H_2S, hydrocarbons and clay and uranium and phosphorous minerals (Ruzicka 1971, Armands 1972). From igneous sources, aids to Mo-U deposition include H_2S, sulphides, changes of pH conditions or decreasing temperatures.

Conclusion

From the foregoing synthesis of the somewhat cursory available information, what is known about the geochemistry of Mo and U points to an expected diadochic association. The two elements display a compatibility throughout a complete range of geologic environments. The transport mechanisms for sedimentary deposits are most likely carbonate complexes and for igneous occurrences, fluoride and chloride complexes. Many porphyry Mo deposits however do not report any uranium values. This may represent a reflection of the relative mobility of the two elements. As U is more mobile, it will tend to migrate further in the igneous hydrothermal plumbing system. Such a zonational theory is supported by vertical zonation in some Russian deposits which are characterized by an increasing U:Mo ratio with decreasing temperature (Rekharskiy and Plyatt 1967). Wallace et al. (1968b) report that brannerite is associated with quartz-sericite alteration above the molybdenum ore at Climax Colorado. Thus much of the molybdenite now exposed in many igneous deposits may be below the zone of U concentration.

CHAPTER 3

Mo-U DISTRIBUTION

Global

The majority of geologic literature dealing specifically with Mo and U association stems from the U.S.S.R. Some 7% of all U deposits within the U.S.S.R. are of the U-Mo type. However, the Soviet publications are notable for their paucity of direct information concerning grades, tonnages and localities. It is never clear whether these deposits occur within a specific metallogenic province, but it is apparent that they constitute a distinct diadochic association.

The occurrences are invariable classed as U-Mo deposits presumably based upon U being more economically important than Mo. If the Russian deposits are similar to those elsewhere, the relative grade of each element will run a complete range from a predominence of uranium to a predominence of molybdenum, varying in some cases within the deposit itself over a vertical and horizontal range.

Russian authors have characterized their deposits under 2 broad classifications namely: (1) Uraninite associated with polymetallic sulphides (including very minor molybdenite), and (2) Pitchblende--molybdenite deposits. The latter genetic classification covers the most common hydrothermal U deposit in the U.S.S.R. In these, the U-Mo association is mostly related to felsic effusives and tuffs but also occurs occasionally within granitoids and granites of Paleozoic age (Ruzicka

1971). Much of the mineralization is either confined to joint systems or to the intersection of permeable horizons with steeply dipping faults.

Other reports on the U-Mo association stem from Canada, the United States, Czechoslovakia, Sweden, India, South Africa, Japan, mainland Australia and Tasmania. Many of the descriptions of Czechoslovakian deposits are similar to those from the U.S.S.R. (Ruzicka 1971). In all cases the association may be found within sedimentary, plutonic or metamorphic environments.

North America

U.S.A.

A wealth of geologic literature concerning sedimentary-hosted U deposits and porphyry copper and/or molybdenum deposits in the western United States show that Mo and U commonly coexist. In the Colorado Plateau and Wyoming epigenetic-diagenetic U deposits, uranium is chiefly located at the interface of "oxidized" and "reduced" sandstone whilst Mo normally accumulates beyond the interface in the reduced sandstone, as ilsemanite (variable Mo oxide) or jordisite (colloidal MoS_2).

Several porphyry copper and/or molybdenum mines have recently discovered small amounts of discrete U minerals, which although of low grade may be recovered under large-scale mining operations. Minor amounts of molybdenite and uraninite are reported as hypogene vein assemblages at Butte Montana, peripheral to the main copper ore bodies. In the Climax Colorado Mo orebody, minor amounts of brannerite are recovered as a byproduct. The breccia pipe orebody of the Orphan Mine in Arizona reports minor molybdenite within its uraninite ores.

In addition, one noteworthy deposit at Marysvale Utah, mines U

and Mo at a ratio of 1:1. The deposit is of the porphyry type and the mineralogy consists of discrete minerals of uraninite, molybdenite and jordisite in the upper levels of the ore-body and as umohoite ($UO_2MoO_4 \cdot 4H_2O$) at depth.

Canada

The U-Mo association has been found in Canada throughout a complete range of geologic environments (with the possible exception of the sedimentary types). According to Vokes (1963) the main molybdenum provinces in Canada are:

(a) the Western Cordillera.

(b) the Canadian Shield (especially the region from south-eastern Manitoba through to southwestern Quebec).

(c) the Appalachian region of the Maritimes.

Within these major provinces one can recognize distinct groupings of smaller subprovinces. The Canadian Shield has long been recognized as a distinct U metallogenic province. However, much of the uranium is accompanied by molybdenum. Thus the Shield might better be classed as a U-Mo metallogenic province.

In the Aillik-Makkovik Bay area of Labrador, Gandhi et al. (1969) and Barau (1970) have described disseminated uraninite with minor molybdenite within Precambrian (Aphebian) metasedimentary/metavolcanic rock horizons and in pegmatites. Barau (1970) is of the opinion that the majority of the U-Mo associations are actually located in metamorphosed felsic volcanics.

Within the Appalachian tectonic belt, Ruzicka (1971) indicates that most of the U-Mo mineralization is related to Devonian intrusions, although a complete range of ages are apparently related to different

tectonic cycles. Little is known of the deposits as many are not fully explored.

In the Grenville Province, the Mo-U association is found throughout a wide range of host rocks. Karvinen (1973) states that most of the better grade U-Mo deposits occur within conformable carbonate lenses along paragneiss contacts. Molybdenum is the only ore element to date as the associated uranium is only of sub-economic grade. Associated vein and pegmatitic deposits are also believed to represent neosome fractions mobilized during metamorphism. Karvinen (1973) believes that the Mo was derived from sediments and transported by chloride-rich solutions.

Baldwin (1970) has described the Lac Turgeon intrusive in the Grenville Province as containing U-Mo separately disseminated and together along joint planes within pegmatites and granites. The almost ubiquitious presence of fluorite with the mineralization is noteworthy.

In the Bancroft area of Ontario, U with minor Mo is associated with pegmatites and leucogranites. Fluorite and calcite are also present.

The Wollaston Lake--Athabasca Basin region of northern Saskatchewan, a major uranium locale, has many occurrences of associated U-Mo. In particular, U and Mo are reported in calc-silicate pegmatites at Cup Lake south of Cree Lake (Munday 1976). Sibbald, Munday and Lewry (1976) describe a calc-silicate unit within the Wollaston Group at Spurjack Island, as containing molybdenite and uraninite in an apatite and fluorite gangue. The Cluff Lake--Carswell Dome U deposits contain minor molybdenite within the breccias of the "N" and "Claude" ore-bodies (Trigg and Woollett 1975).

Further north in the Beaverlodge--Black Lake area of northern Saskatchewan, Morra (1977) has described a positive correlation between U and Mo within granodioritic granofelses and migmatites of the Charlebois Lake region. Uraninite is the major mineral and occurs with molybdenite in ratios averaging about 2.5:1. Morra (1977) believes the mineralization was a pre-metamorphic syngenetic-sedimentary association which was in part mobilized into neosome fractions. Recently Kintla Exploration Ltd. has announced the association of uranium with molybdenite in pegmatites in the Pluto Bay area of northern Saskatchewan.

The Central Plains of Saskatchewan and Alberta contain U occurrences in lignites of the Cypress Hills (Ruzicka 1971). To date however, no occurrences of associated Mo have been reported. An analagous situation to the Cypress Hills exists in the Mt. Billingen area of Sweden where Armands (1972) has described U and Mo fixed within uranyl humates contained within alum shales of Cambrian age. The contained U of the Cypress Hills and Mt. Billingen is similar averaging 0.42 lb U_3O_8/ton and 0.6 lb U_3O_8/ton respectively. Uraniferous lignite deposits in western North Dakota average 0.02% U_3O_8. Burning of the lignites produces an ash containing 0.5% U_3O_8 and 0.3% MoS_2 (Woodmansee 1975).

Recently, the Wernecke Mountains area of the Yukon has become a target for U exploration. U and Cu mineralization are localized in sedimentary and volcanic breccias in Helikian rocks. Uranium as brannerite and pitchblende, is disseminated or in veinlets with associated chalcopyrite. Molybdenum is anomalously high with the radioactivity (Morin 1976).

Mo-U Deposits in B.C.

Occurrences of molybdenite and uranium minerals regardless of their proportions, are shown on Map 1. Brief geological descriptions are presented below:

Abe--Granites of the Topley Intrusions (Cretaceous) are cut by irregular quartz porphyry and rhyolite porphyry and diabase dikes. Molybdenite occurs as disseminations within strongly silicified and sericitized granite and more abundantly within widely-spaced quartz veins cutting the granites. Secondary uranium minerals are present in fractures within the rhyolite porphyry (G.S.C. "Molyfile")[1].

Annette--Molybdenum, uranium and tungsten minerals occur in quartz veins and fractures cutting the Horsethief stock and are disseminated through Purcell metasediments along the stock contact (GEM 1971, p. 426)[2].

Beaver--Granite and granodiorite are intruded into metasedimentary and metavolcanic rocks. Molybdenite and uraninite with associated galena and fluorite are localized in amphibolite bodies thought to be metamorphosed, calcareous volcanic agglomerates (BCAR 1953, p. 79)[3].

GEM--Granodiorite of the coastal intrusive suite is cut by feldspar porphyry dikes. Mo-U mineralization is restricted to pegmatite lenses occurring in bleached and sericitized granodiorite. Molybdenite and uraninite occur in association with other sulphides (BCAR 1948, p. 112).

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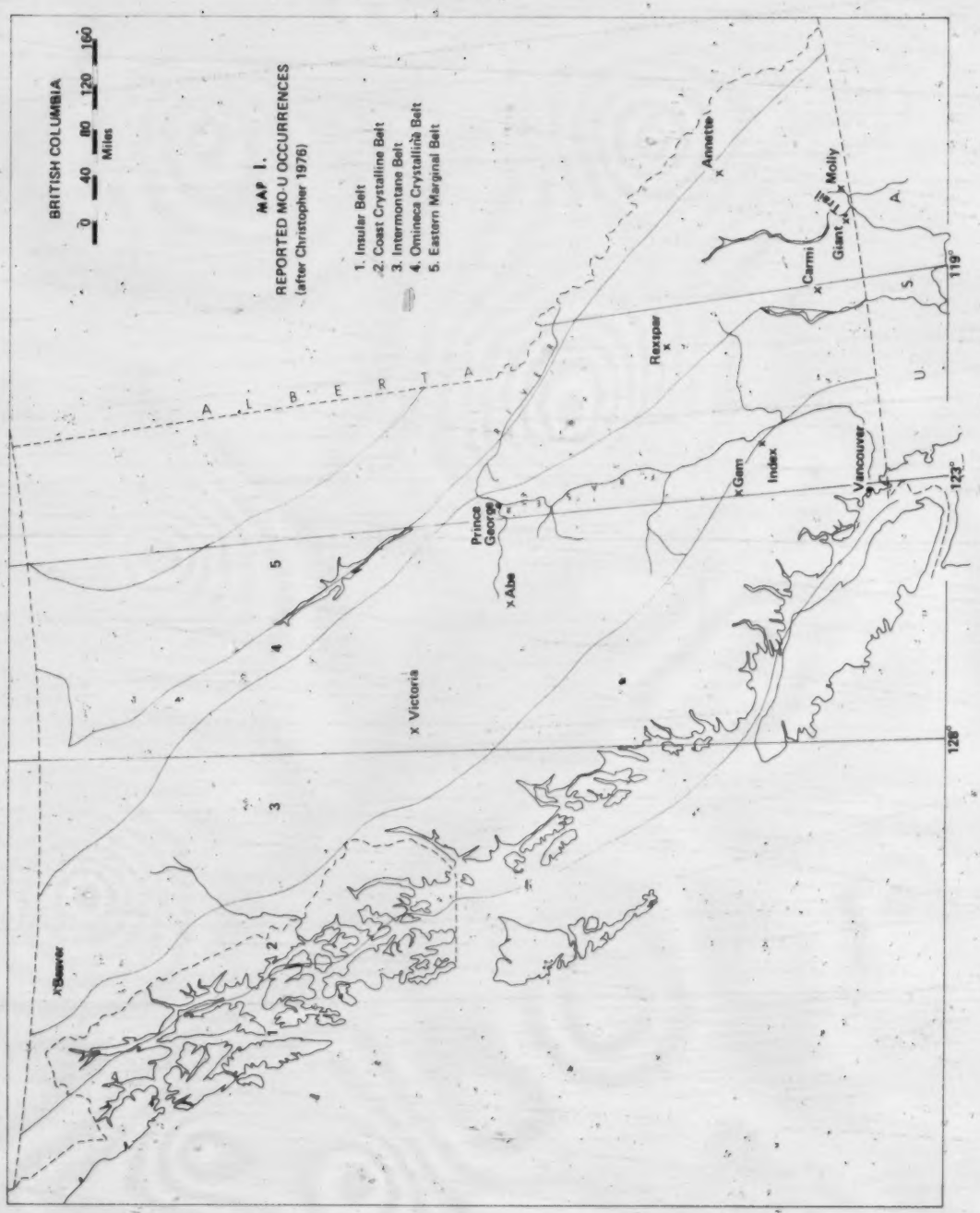
[1] G.S.C. "Molyfile"--computer printout of molybdenum occurrences in Canada.

[2] GEM--Geology, Exploration and Mining in British Columbia. Published by the B.C. Dep. Mines.

[3] BCAR--British Columbia Minister of Mines Annual Report.


BRITISH COLUMBIA
0 40 80 120 160
Miles
MAP I.
REPORTED MO-U OCCURRENCES
(after Christopher 1976)
1. Insular Belt
2. Coast Crystalline Belt
3. Intermontane Belt
4. Omineca Crystalline Belt
5. Eastern Marginal Belt
ALBERTA
Annette
Molly
Carmi
Giant
Rexspar
Gem
Index
Vancouver
Prince George
Aba
Victoria
Beaver
119°
123°
128°
1
2
3
4
5

Giant--Metasedimentary rocks are intruded by Eocene intermediate igneous rocks, intrusive breccias and late stage lamprophyre dikes. Molybdenite and lesser amounts of uraninite occur with other sulphides as pockets and disseminations within the andesitic breccia matrix. They occur much less frequently within the breccia blocks (BCAR 1966, p. 200).

Index--A Mesozoic granite stock intrudes metasediments. Molybdenite occurs as fracture fillings and joint coatings and as minor disseminations within the stock. Low-grade uranium mineralization occurs as sporadic disseminations near joints and shears. It appears that molybdenite predates the uranium (BCAR 1949, p. 113).

Molly--Molybdenite occurs in fractures and shear zones in a granitic phase of the Nelson Batholith. The opaque mineral assemblage is similar to that of the Index property. Hydrothermal alteration of the intrusion is apparent. Pyrite, pyrrhotite and chalcopyrite are associated with the U-Mo mineralization (GSC Econ. Geol. Ser. 16 1952, p. 45).

Rexspar--Highly faulted trachytic tuffs and flows overlie Paleozoic quartz-sericite schists with interbedded carbonaceous and phyllitic units. Uraninite occurs within tabular, fault-controlled zones cutting a trachyte porphyry. Uraninite is associated with mica, pyrite and fluorite. Minor molybdenite is also reported (BCAR 1954, p. 108).

Victoria--Granodiorite and quartz diorite of the Rocher Deboule Batholith intrude quartzite and limestone. Mineralization occurs within a hornblendite vein containing pegmatitic material. Sulfarsenides occur within a hornblende gangue but molybdenite and uraninite occur as crystal clusters and disseminations within felsic pegmatite lenses (BCAR 1949, p. 82).

The most significant Mo deposits of the Canadian Cordillera are

encountered within the Intermontane Tectonic Belt with the next most significant groups occurring near the borders of the Intermontane Belt with the Coast Crystalline Belt and the Omineca Crystalline Belt. Seven of the 35 significant deposits occur within the Omineca Crystalline Belt, chiefly in the far northern and southern sectors (Soregaroli, Sutherland Brown 1976).

Of the 10 reported Mo-U occurrences only Abe, Index, Gem and Carmi may be classed as porphyry-type deposits with either breccia or stockwork mineralization. The other seven prospects, although related to calc-alkaline magmatism, represent either peripheral vein deposits, post-intrusive dike activity, or xenolithic mineralization. Five of the deposits are within the Omineca Crystalline Belt, including the Rexspar deposit which may represent a high level calc-alkaline porphyry situation. However, since it is obvious that Mo and U are an established association, it remains probable that the majority of the 35 significant Mo deposits in B.C. have not as yet been tested for U mineralization, or as an alternative, the molybdenite mineralized outcrops which first attracted exploration attention have been eroded below the higher level zone of U deposition.

CHAPTER 4

CARMI EXPLORATION HISTORY

In 1960, Kennco Explorations (Western) Ltd. conducted reconnaissance stream sediment geochemistry in the Slocan-Omineca belt and defined anomalous Mo values in the Beaverdell district. Follow-up work outlined the Tuzo Creek and Carmi areas as sources.

Tuzo Creek was initially explored by Kennco and subsequently by Amax Explorations Inc.; the latter corporation still retaining claim groups in the area. Carmi was also staked by Kennco and subsequent work involved soil geochemistry, geophysics and diamond drilling. All but four claims (the DOE group) were allowed to lapse.

International Minerals Corporation (IMC) performed geological work during 1969 and 1970 and drilled 14 diamond drill holes to test geophysical targets. Although 6 of the holes intersected high-grade molybdenite over considerable widths, the property option was terminated.

Husky Minerals and G.V. Lloyd Explorations optioned the four DOE claims from Kennco and the surrounding claims from two local prospectors and spent the field seasons of 1971 to 1973 performing assessment work. This included geological interpretation and some geochemistry and geophysics. The results of this program were not considered encouraging and the property was returned to the owners.

In 1974, Vestor Explorations Ltd. obtained the claim groups surrounding the major showings and negotiated with Kennco Explorations

for rights to the DOE group. During 1974 Vestor drilled approximately 5600 feet (1700 m) of core in 17 diamond drill holes and did 2000 feet (605 m) of percussion drilling. Based upon the encouraging results obtained, Granby Mining Corporation optioned the property from Vestor in late 1974 and by the close of 1975, had completed an additional 15000 feet (4540 m) of percussion drilling in 40 holes.

By this stage, the "E" zone had been well drilled and shown to contain an estimated 30 million tons of ore-grade molybdenite. The "Lake" zone had only been superficially tested but showed grades within the same range.

The Granby-Vestor agreement was terminated in 1976 and the property was optioned by Vestor to Craigmont Mines Ltd. During 1976 Craigmont drilled 3400 feet (1030 m) in 12 percussion holes in areas adjacent to known mineralization. In 1977 an additional 4100 feet (1242 m) of diamond drilling was completed.

To date, some 32000 feet (9090 m) of drilling on the property has confirmed the existence of 2 distinct mineralized zones: the "E" zone containing drill-indicated reserves of 30.5 million tons of mineralized rock at a grade of 0.157% MoS_2, and the "Lake" zone with drill-indicated reserves of 7.3 million tons of 0.128% MoS_2. The total of the two zones yields 38 million tons (34.5 million tonnes) of 0.151% MoS_2. The associated U mineralization remains at present of sub-economic grade and is restricted to a small part of the "E" zone breccia.

Calculations of reserves were computer derived by two independent mining companies. However, it should be pointed out that David et al. (1977) believe that reserve calculations based upon cut-off grade block models do not give accurate predictions of tonnages. They state that a geostatistical approach must be used to establish the correct ore to

waste ratio within each block so that each tonnage block has accurately determined grade classes. It should also be pointed out that molybdenum deposits have a history of underestimation. That is, mining grades are generally higher than drill indicated grade, due to molybdenite being easily abraded from and washed out of diamond drill core. The significance of the Carmi deposit with respect to major North American Mo deposits is presented in Appendix I.

Carmi Regional Geology

The town of Carmi is located close to the border of the Omineca Crystalline Belt and the Intermontane Belt, and lies within the former. The area was mapped by Little (1957, 1961) but no comprehensive publication exists concerning the geology. The Vernon map sheet (GSC 1059A) to the north and the Nelson district to the east (GSC 603A, GSC 82F W1/2) have been discussed by Jones (1959), Rice (1961) and Little (1960).

According to Little (1957), sedimentary and igneous rocks both intrusive and extrusive, ranging in age from Precambrian to Tertiary are exposed in the district (Map 2).

The Precambrian sequence consists of low-to medium-grade metamorphic rocks of the Monashee and Chapperon groups, cut by serpentinized ultrabasic dikes. The Monashee group is exposed only as small isolated roof pendants with-in the Nelson Batholith but is the predominant rock unit over large areas to the west and north of Carmi.

Paleozoic rocks within the district are represented by sediments, volcanics, and low-grade metamorphics of the Kabau, Cache Creek and Anarchist Groups and by the Blind Creek and Mount Roberts Formations. Of these units, the Anarchist Group predominates, but large areal expanses

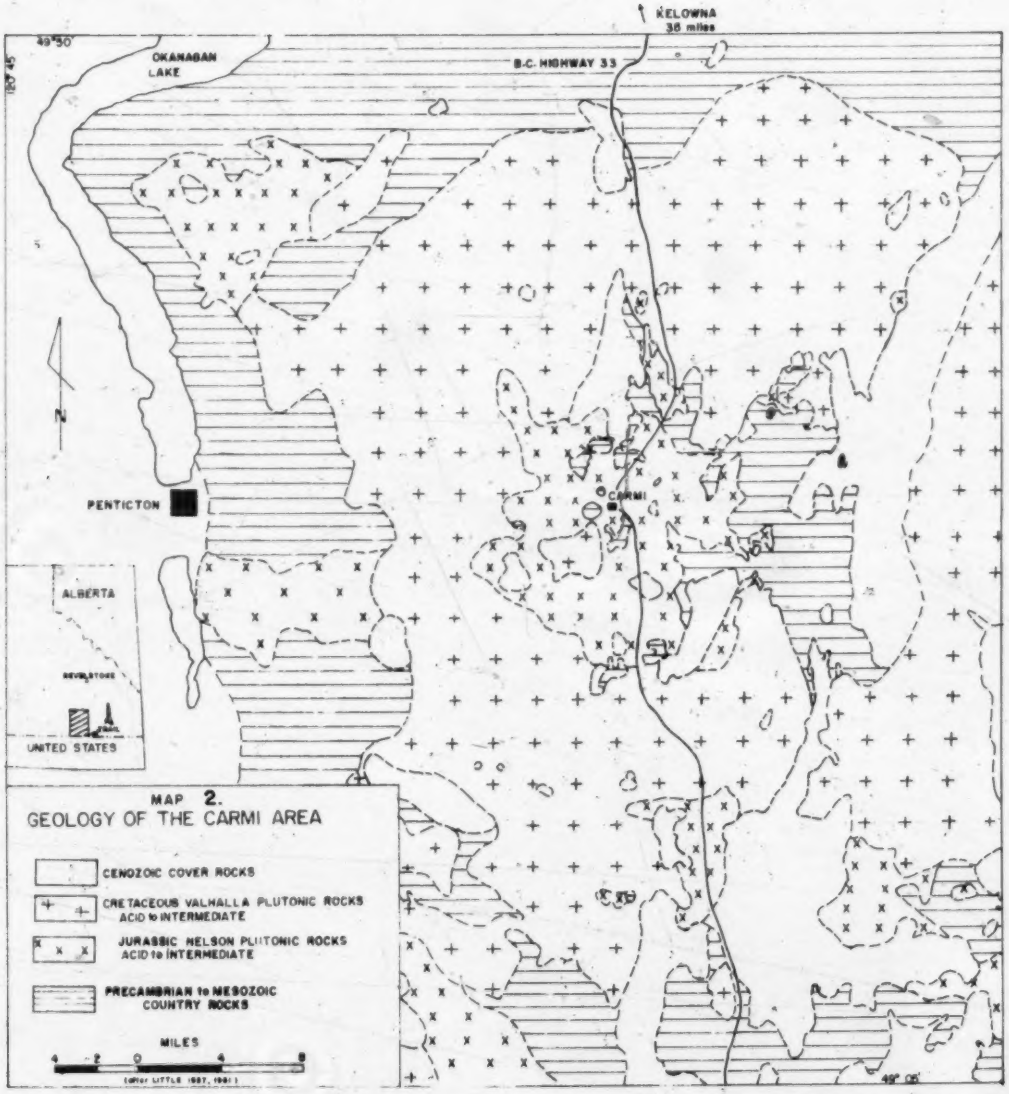

KELOWNA
38 miles
49°50'
OKANAGAN LAKE
B.C. HIGHWAY 33
119° 45'
N
PENTICTON
CARMI
ALBERTA
UNITED STATES
MAP 2.
GEOLOGY OF THE CARMI AREA
CENOZOIC COVER ROCKS
CRETACEOUS VALHALLA PLUTONIC ROCKS ACID to INTERMEDIATE
JURASSIC NELSON PLUTONIC ROCKS ACID to INTERMEDIATE
PRECAMBRIAN to MESOZOIC COUNTRY ROCKS
MILES
4 2 0 4 8
49° 00'

TABLE OF FORMATIONS

Period	Formation	Lithology
Pleistocene		glacial debris, silt, clay, lake and stream sediments.
Tertiary	unnamed	plateau basalts, olivine basalts.
	Coryell Plutonics	syenite, granite, monzonite, shonkinite.
	Phoenix Volcanics?	andesite, trachyte, tuff shale, siltstone.
	Kamloops Group?	andesite, trachyte, basalt, sandstone, breccia, conglomerate, coal.
	unnamed	granite, rhyolite.
	Kettle River Formation	conglomerate, shale, sandstone, tuff.
Cretaceous	Valhalla Intrusion	granite, quartz monzonite
Jurassic	Nelson Batholith	granodiorite, quartz diorite, quartz monzonite, syenite, diorite.
	unnamed	pyroxenite, serpentinite.
	unnamed	limestone.
Triassic	Nicola Group	basalts, tuff, breccia, conglomerate, limestone.
	Slocan Group?	argillite, volcanics, schist, minor gneiss.
Permian	Anarchist Group	greenstone, limestone, quartzite, paragneiss.
	Mt. Roberts Formation	greywacke, greenstone, limestone.
	Cache Creek Group	argillite, quartzite, limestone, greenstone.
	Blind Creek Form.	limestone, argillite.
Carboniferous	Kobau Group	quartzite, greenstone, schist.
Precambrian	Old Dave Intrusives	serpentinized ultrabasics.
	Chapperon Group	chlorite schist, quartzite.
	Monashee Group	paragneiss, schist, marble, amphibolite.

modified after Jones (1959), and Little (1957, 1960, 1961)

are confined mostly to the east and south east regions of the map sheet. Around Carmi, large tracts of the Anarchist Group occur as roof pendants within the Nelson Batholith or along the Nelson--Valhalla complex contact. It is within these pendants that mineralized shear zones were mined in the 1920's for their precious metal content.

Rocks of Mesozoic age are represented by sediments, volcanics, metamorphic and intrusive units. The intrusives are chiefly the Nelson and Valhalla Batholiths. Exposures of older Mesozoic sedimentary and volcanic rocks of the Slocan and Nicola Groups and as yet unnamed units, are few and generally restricted to roof pendants. The best exposures are available to the north and west of Carmi where these strata overlie the Nelson Batholith.

Cenozoic units in the district are represented by poorly indurated or well-cemented sedimentary rocks, volcanics and intrusive suites. The basal Kettle River Formation crops out south of Carmi but is restricted to river valleys. The granitic and syenitic stocks of the Coryell and Shephard Intrusives represents the last orogenic event and are tentatively estimated to be about 30 million years old on the basis of lithologic relationships alone (Little 1960). Plateau basalts remain in part as cappings to the north of Carmi and recently have been the object of exploration interest where these basalts cover loosely-consolidated uraniferous fluvial gravels. Pleistocene glaciation scoured all areas below 7500 feet (2272 m) elevation. The ice moved in a southerly direction (Little 1957).

Regional Structure

In general, the tectonic structure of the Canadian Cordillera is dominated by the effects of the Columbian and Pacific Orogenies. The Columbian Orogeny had its core zone in the Omineca Crystalline Belt and is represented by the Shuswap Metamorphic Complex (Wheeler et al. 1972). The western boundary of the Shuswap Complex lies some 20 miles east of the Carmi region.

According to Wheeler et al. (1972), the Columbian Orogeny lasted from mid-Triassic to early Tertiary times. Related metamorphism in the Shuswap Complex is at least as old as Lower Jurassic. Discordant granitic plutons associated with the Columbian Orogeny are mostly concentrated in or around the Shuswap Complex core zone. K-Ar age determinations show an age range of from 185 my to 60 my (Wheeler et al. 1972). The Nelson Batholith, which straddles the boundary of the Shuswap Complex has K-Ar ages ranging from 165 my to 136 my (Nguyn et al. 1968, Douglas et al. 1970, Wheeler et al. 1972). According to the aforementioned authors, late tectonic intrusives, chiefly granodiorite, occur at or near the edges of the Shuswap Complex with an associated outer ring of intrusives of mainly quartz monzonite. This outer ring gives K-Ar ages of 90 my to 110 my (Wheeler et al. 1972). Therefore, the emplacement of plutons occurred over a considerable length of time from approximately 185 my to 60 my ago and are considered to have evolved as a result of successive pulses (Gabrielse and Reesor 1964, Baadsgaard et al. 1961). The Valhalla metamorphic and plutonic complex is also attributed to the time period of the Columbian Orogeny. According to Reesor (1965) seventeen K-Ar age determinations from different localities within the Valhalla

complex have returned ages of from 66 my to 11 my. Reesor (1965) believes that the oldest dates may represent the last major penetrative structural deformation associated with the Columbian Orogeny which gave rise to the Valhalla event. He further states that this may represent a time spread of 100 my between the Nelson stage of deformation and emplacement, and the emplacement of the Valhalla complex.

Reesor (1965) concluded from field evidence that neither a simple magmatic injection nor an in situ transformation could account for the Valhalla and thus proposed a complex evolution involving both aspects and a subsequent reworking of earlier stages, by a later series of events. The Nelson Batholith was apparently unroofed in late Lower Cretaceous as evidenced by igneous pebbles in the middle Lower Cretaceous McDougall-Segur conglomerate of the Blairmore Formation in the Kootenay region (Little 1960).

As a result of the Columbian Orogeny, the Omineca Crystalline Belt is characterized by intense multiple folding, thrusting and high-angle faulting (Sutherland Brown et al. 1971). Most of the major faults in the southern portion of that belt appear to be tangential to the plutonic rocks and at times radial to them (Little 1960).

Geology of the Nelson Batholith

Both the eastern (Rice 1941) and western (Little 1961) borders of the Nelson Batholith appear similar. It is composed of a pinkish granodiorite grading into a grey granodiorite near the margins. The granodiorite phase in the Nelson map area ... "is a greenish grey, coarse-to medium-grained quartzose rock in which the feldspar is largely plagioclase and biotite is much less abundant than hornblende" (Little

1960, p. 83). Much of the rock is foliated and the texture is hypidiomorphic. Other identified differentiates in order of decreasing abundance are: quartz diorite, quartz monzonite, diorite, monzonite and syenite (ibid). Numerous smaller plugs and dikes of varying intermediate to acid composition occur. Their origin has been ascribed by Little (1960) to satellite facies of the porphyritic granite core of the intrusive, probably implying some magmatic differentiation and/or melt incorporation of the country rock.

Geology of the Valhalla Batholith

Where the relationships of the Nelson and Valhalla can be observed, the Valhalla everywhere cuts, or is gradational to the Nelson and was assumed to be younger (Little 1960). The type geology as described by Little (1960) shows the Valhalla to be an essentially white to pinkish, foliated rock ranging from granite to quartz monzonite, with biotite and muscovite being the predominant mafics. The quartz is invariably of smoky aspect and Little (1960) originally believed that this may have been due to radioactive bombardment, but subsequent analyses showed that both the Nelson and Valhalla contained only normal U_3O_8 concentrations for acidic rocks. The texture of the Valhalla is allotriomorphic.

Because of the differentiating nature of the two intrusives the type geology descriptions do not appertain to the entire extent of the batholiths. Rock textures ranging from massive to foliated and fine-grained to porphyritic have been reported (Cairnes 1934, Little 1960).

The following chemical analyses by Cairnes (1934) and by Little (1960) indicate the apparently differentiated nature of the two intrusives, lending credence to the hypothesis that they are in fact differentiated phases of one large, common magma source (Table 2).

TABLE 2

CHEMICAL ANALYSES OF NELSON AND VALHALLA INTRUSIONS

	NELSON'		VALHALLA*	
	porphyry	granodiorite	quartz monzonite	
SiO_2	65.60	66.46	70.78	72.13
Al_2O_3	17.23	15.34	15.64	14.71
Fe_2O_3	1.50	1.68	0.56	0.58
FeO	1.40	1.83	1.02	1.16
CaO	3.04	3.43	2.06	1.61
MgO	1.00	1.11	0.52	0.46
Na_2O	5.35	4.86	4.31	3.93
K_2O	3.40	4.58	3.82	4.45
H_2O	0.80	0.29	0.52	0.54
TiO_2	0.20	0.27	0.27	0.26
P_2O_5	n.a.	0.08	0.14	0.12
MnO	0.12	n.d.	0.05	0.05
CO_2	n.d.	n.d.	0.04	0.01
	99.54	99.93	99.73	100.01

'after Cairnes 1934 n.d.--not detected

*after Little 1960 n.a.--not analysed

CHAPTER 5

PETROGRAPHY OF THE INTRUSIVE ROCKS

Introduction

The granodiorite phase of the Nelson Batholith is the principal igneous unit of interest in the Carmi area. In the course of mapping and examination of diamond drill core, several other rock units were distinguished. Among these were quartz dioritic and quartz monzonitic phases of the Nelson Batholith and a deeper, barely exposed quartz monzonitic intrusion tentatively correlated with the Valhalla Batholith. Derivatives of the Valhalla include pegmatite and quartz veining and matrix cement of the breccia bodies, feldspar porphyry and perhaps lamprophyre dikes.

The geology of the Nelson Batholith has been well described by Cairnes (1934), Rice (1941) and Little (1961). The deeper quartz monzonite intrusion is tentatively correlated with Valhalla plutonic rocks based upon mineralogic and textural similarities to the rocks of the type area described by Little (1960) and upon the relationships between the quartz monzonite and the overlying Nelson pluton.

The Anarchist Group country rocks, adjacent to and partially overlying the Nelson, have been thermally and regionally metamorphosed producing biotite schists, greenstones, quartzites and locally some hornfels. The country rock has been intruded by thin sills and dikes of leucocratic granitic rock ranging from massive to slightly foliated.

Some xenoliths of country rock are evident within the Nelson. The local geology is presented on Map 7 (pocket).

The Nelson Granodiorite

The Nelson granodiorite is the oldest intrusion in the area. It constitutes, with quartz diorite, the brecciated host for the Mo-(U) mineralization. The Nelson granodiorite is a melanocratic, medium grained, hypidiomorphic granular, slightly-to well-foliated rock. In hand specimen, the feldspars may be either pink or white, regardless of composition.

Plagioclase (50-75%) occurs as subhedral, 1-4 mm sized, partially altered grains twinned on the albite, carlsbad and pericline laws. Some zoning is evident and gives a normative compositional range of An_{32} to An_{40}. Plagioclase shows minor patches of exsolved microcline and contains small inclusions of quartz, fluorite and opaques, all of which are anhedral. Intumescent myrmekite has developed between adjoining plagioclase and microcline.

Quartz (5-20%) is anhedral, grain size 1-2 mm, often elongate and is interstitial. It is most often cracked and fractured and displays undulating extinction. Numerous fluid inclusions of the liquid plus gas type are apparent.

Potassic feldspar (5-20%) occurs as orthoclase and microcline, with the latter being much more abundant. Both feldspars are anhedral, 3-6 mm grains with embayed outlines. Some of the potassic feldspar contains exsolved plagioclase. The feldspars are fresh with only traces of alteration along some cleavage planes. There is some evidence that orthoclase was converted to microcline from the interrelationship of the two minerals. Smith (1974) believes that cross-hatched microcline results

from the inheritance of twin elements of early monoclinic orthoclase.

Biotite (3-11%) occurs as subhedral, equidimensional to elongate crystals of 1-5 mm in size. Grain terminations are generally shredded and incipient chloritization has developed travelling up crystal cleavages. Chloritization has produced oxides either included in biotite grains or close to grain boundaries.

Accessory minerals include epidote, muscovite, titanite, apatite and zircon in order of decreasing abundance. Epidote and muscovite are secondary minerals, and are discussed under "Alteration".

The Nelson Quartz Diorite

The surficial extent of the quartz diorite phase of the Nelson intrusion is not known. Its occurrence is largely confined to breccia fragments within the "E" zone breccia seen within diamond drill core. Short intervals of well-foliated quartz diorite have been identified within more massive granodiorite. It is suggested that it is a magmatic fractionation product of the granodiorite. The volume of quartz diorite fragments within the breccias does not correlate with the volume observed outside the breccias. Therefore it is proposed that the major portion of the quartz diorite fragments are allochthonous.

The mineralogy of the quartz diorite is essentially the same as the granodiorite apart from relative abundances. Plagioclase (55-75%) is anhedral to subhedral and the 2-5 mm sized grains are twinned on the albite and pericline laws. It is often zoned and shows a compositional range of An_{29} to An_{35}. Fluorite and opaques occur as tiny inclusions. Quartz (10-20%) is nearly always elongate regardless of grain size (2-5 mm). It is fractured and may contain tiny inclusions of plagioclase.

Biotite (5-10%) occurs as light brown, anhedral to subhedral grains showing traces of chloritization. Accessory minerals include all of those listed for granodiorite with the addition of hornblende. Within the breccia, quartz diorite fragments are quite altered with the production of secondary epidote, carbonate and muscovite due to pervasive quartz-sericite alteration.

The Nelson Quartz Monzonite

The occurrence of the Nelson quartz monzonite is ascribed to a satellite phase of the Nelson Batholith. No interrelationships between the Nelson quartz monzonite and the Valhalla quartz monzonite have been observed, and where the Nelson quartz monzonite cuts the Nelson granodiorite, no chill effects in either rock unit were observed. Also, the An content of plagioclase feldspars is much more similar to that of the Nelson granodiorite than to that of the Valhalla quartz monzonite.

The Nelson quartz monzonite occurs as thin veins and dikes to the east of the "Lake" zone breccia and as a pod of unknown vertical extent to the north of the same breccia. In hand specimen it is a leucocratic, medium to coarse grained, allotriomorphic granular rock often showing trachytic texture. Rock composition varies from quartz monzonite to granite but is consistently off-white in color. The color index rarely exceeds 2%.

Plagioclase (30-50%) with 1-3 mm sized grains, is anhedral and of composition An_{35} to An_{40}. It is twinned on the albite and pericline laws. Zoning is not apparent but mineral alteration has affected the interior of the plagioclase much more than the grain rims. Sericitization has progressed along cleavage planes nearly perpendicular to twin

planes. Myrmekite is abundant where plagioclase abuts microcline grains.

Potassic feldspar (35-60%) grains may range in size up to 10 mm and are anhedral and display a fluxion structure of elongate grains. It is entirely microcline, with some grains showing perthitic intergrowths of non-oriented plagioclase. Alteration has not affected microcline but minor inclusions of quartz are present.

Quartz (10-15%) averages 3 mm in size, is anhedral and interstitial. It often displays an interlocking, sutured habit with other quartz grains. Its initial abundance has been enhanced by subsequent myrmekite developments.

Accessory minerals include biotite, muscovite and opaques. Biotite (< 2%) occurs as subhedral, green to brown laths with incipient chloritization progressing along cleavage. Muscovite and magnetite occur as trace constituents in the matrix.

The Valhalla Intrusion

Introduction

The intrusion of the Valhalla quartz monzonite provided the mechanism for brecciation of the overlying Nelson granodiorite. In addition, subsequent hydrothermal events associated with the Valhalla intrusion gave rise to the metallic mineralization. Late-stage derivatives of the Valhalla intrusion include pegmatite and quartz veining, breccia quartz and quartz-feldspar cement, feldspar porphyry and perhaps lamprophyre dikes.

Surface exposures of the principal quartz monzonite intrusion are non-existent. Information concerning this unit comes chiefly from diamond drill intersections. The feldspar porphyry dikes are known from

lengthy surface exposures in the "Lake" zone and from drill intersections in the "E" zone. Quartz and pegmatite veining have been observed in outcrop but lamprophyre dikes are known only from diamond drill intersections.

The Valhalla Quartz Monzonite

The Valhalla quartz monzonite is a leucocratic, medium grained, hypidiomorphic granular, slightly porphyritic rock. Plagioclase (35-45%) of composition An_{27} to An_{35} is subhedral to euhedral with discontinuous zoning and is twinned on the albite and carlsbad twin laws. It is occasionally porphyritic with grain sizes to 5 mm, and has been partially sericitized in the more calcic crystal centers. Minor inclusions of epidote, quartz, chlorite and fluorite are present along with traces of exsolved potassic feldspar. In hand specimen, the plagioclase displays both white and pink coloration.

Potassic feldspar (30-45%) occurs as anhedral, 1-3 mm sized grains which are interstitial relative to plagioclase. Both orthoclase and microcline are present but microcline is most abundant. Myrmekite is more abundant than in the Nelson granodiorite and has well-developed rod and dendritic quartz inclusions. Alteration, apart from embayed margins, is non-existent.

Quartz (5-20%), is anhedral but with traces of bipyramidal development and exhibits undulatory extinction. Grains are 1-2 mm in size.

Both biotite (2-8%) and muscovite (1-5%) occur as subhedral laths 1-3 mm long. Biotite ranges from brown to green-brown and displays frayed grain ends. Much of the biotite is very chloritized and has resulted in oxide development. Muscovite appears to be later than biotite.

Hornblende (2%) occurs as anhedral, partly choloritized grains 2-4 mm long. It had formed earlier than biotite and is occasionally intruded by that mineral. Accessory minerals of 1% or less include, zircon, apatite, titanite, sillimanite, fluorite and traces of molybdenite rosettes.

The Feldspar Porphyry Dikes

The feldspar porphyry dikes are correlated with the Valhalla quartz monzonite on the basis of mineralogic and textural similarity. The composition of the feldspar porphyry ranges from quartz monzonite to granite from south to north exposures in the "Lake" zone. Drill intersections in the "E" zone are quartz monzonite.

Plagioclase (20-50%) occurs as 1-8 mm, predominantely euhedral phenocrysts of composition An_{20}. Phenocrysts show moderate alteration on zoned crystal rims. This feature may indicate reverse zonation. The crystals are twinned on the albite and carlsbad laws. Where the feldspar porphyry dike is of granitic composition, plagioclase phenocrysts show potassic feldspar mantling. Alteration is primarily a result of late magmatic fluids that have in some cases obliterated plagioclase twinning and produced multiple amoeboid quartz inclusions. Myrmekite has partially developed around plagioclase phenocrysts.

Orthoclase (40-70%) occurs as the microcrystalline, often radial textured, ground mass. Rare phenocrysts of orthoclase (to 3 mm) may be the result of plagioclase replacement or the dual crystallization of plagioclase and orthoclase prior to dike injection.

Quartz (5-8%) occurs as 1-3 mm subhedral grains occasionally reaching a porphyritic 5 mm size. Typically it shows the spherulitic

to rectangular "corroded quartz" texture with intruded lobes of matrix common to porphyries. Quartz phenocrysts may contain imbedded, slightly altered plagioclase crystals.

Biotite (3%) is subhedral to euhedral with grains between 1 and 3 mm. They are brown and display both rectangular and elongate habit. Chloritization has progressed to some extent in all grains. Chlorite is more abundant than biotite in the northern dike exposures, and the transformation has produced anhedral fine grained oxides.

Accessory minerals of 1% or less include zircons (in matrix), fluorite (in plagioclase and matrix) and opaques. Opaque minerals are sulphides and oxides of which oxides are more abundant. All the metallic minerals are anhedral and usually about 1 mm across. Some magnetite grains show hematite rims.

Lamprophyre Dikes

Very altered, basic dikes, never exceeding 10 foot (3 m) thicknesses, have been drill intersected in all rock units except the feldspar porphyries. The source of the dikes remains uncertain. They may represent late-stage basic fractions of the Valhalla pluton or they may be representative of Tertiary volcanism. Many Tertiary basaltic dikes are known to cut Valhalla and Nelson rocks west of Carmi (pers. com. Dr. G. Krupicka).

Due to the extremely altered nature of the dikes, some of the mineralogic descriptions may not be exact. The dikes approximate to spessartite lamprophyres.

Small phenocrysts (to 3 mm) of pyroxene (probably diopside) compose 15% of the rock and have been rounded and altered to essentially chlorite and carbonate. Several percent of these phenocrysts may be

rounded olivine grains.

The groundmass is composed of basaltic hornblende (25%), and microcrystalline albite (60%) with traces of potassic feldspar. The basaltic hornblende occurs as tiny subhedral to euhedral laths altered to chlorite and carbonate minerals. They display a fluxion alignment. The microcrystalline albite groundmass shows radial patterned grains. Some carbonate occurs along fractures. It is suggested that the intense alteration resulted from late-stage magmatic fluids carried by the dike as shearing produced alteration is non-existent.

CHAPTER 6

ALTERATION OF INTRUSIONS

The intrusions of the Carmi deposit have been affected by hydrothermal processes ranging from slight to intense. Thus mineralogic alteration will be attributed to hydrothermal events even though deuteric alteration has no doubt taken place. In thin section it is nearly impossible to distinguish between minerals formed by the two processes.

All igneous rock types have been affected to some degree. Most well-pronounced alteration occurs within the breccia zones which have acted as the principal conduits for the hydrothermal fluids (see Plate 1).

Hypogene alteration includes extensive propylitic alteration, quartz-sericite (phyllic) alteration largely coincident with the breccia zones, and subtle, very minor potassic alteration apparently restricted to the "E" zone breccia. The alteration sequence and mineralogy may not follow the classical porphyry system but ... "the alteration sequence developed in a particular deposit can be explained in large part as a function of position of the deposit within a convecting "ore-fluid" system..." (Drummond and Godwin 1976, p. 61).

Propylitic Alteration

Propylitic alteration includes the development of secondary epidote and chlorite as its chief characteristics. Propylitic alteration may be partially a regional metamorphic effect as well as a local alteration effect. The regional metamorphism required to produce the foliation

of the Nelson granodiorite may have contributed significantly to the development of epidote. Propylitic alteration extends well away laterally and vertically from the breccia zones to include unfractured Nelson granodiorite laterally and occasionally, massive Valhalla quartz monzonite vertically. Characteristics include flecks and ragged granules of epidote contained as inclusions within plagioclase crystals, formed as a result of the breakdown of the host plagioclase. In many instances epidote has been mobilized into foliation planes with biotite. The epidote never shows crystal outlines and is invariably cracked. The biotite displays chloritization ranging from incipient along ends and cleavage planes to chlorite being more predominant than biotite.

Carbonate is ubiquitous as irregular patchy inclusions in plagioclase, as thin veinlets in fractures and as patches in the quartz matrix. The propylitic alteration boundary is not presented on the cross-sections (in pocket) as it occurs completely throughout the Nelson granodiorite as mapped on the cross-sections and is rarely present by itself in the breccia zones.

Quartz-Sericite Alteration

Quartz-sericite alteration is largely coincident with molybdenite mineralization. Where fractured granodiorite underlies the granodiorite breccia, quartz-sericite alteration has penetrated outward as thin selvages of sericite along quartz and quartz-feldspar veining. Here, propylitic and quartz-sericite alteration overlap. Within the breccia proper, quartz-sericite alteration exhibits a range of intensity from weak to very intense. Weak to moderate alteration affected all fragments and is characterized by sericitized and saussuritized plagioclase with

clouding or complete elimination of twin elements. Patchy carbonate occurs in all plagioclase and has moved into the matrix. Plagioclase grains have been corroded and embayed by lobes of quartz matrix. Potassic feldspar as orthoclase or microcline shows thin lines of sericite development along cleavage. Quartz has been enhanced and recrystallized as evidenced by new growths around older more rounded-appearing grains. Biotite displays frayed grain ends with chloritization growing up the lamellae and often with associated sericite. Muscovite has developed as an alteration product and grows into or overlays all minerals.

Very intense quartz-sericite alteration has obviously occurred along major channelways of the hydrothermal system. Its development is characterized by the almost total destruction of feldspars and the introduction of quartz, minor green hydrothermal biotite, and the development of massive muscovite and introduction of associated fluorite. The "Lake" zone breccia is more affected by intense quartz-sericite alteration than is the "E" zone.

Potassic Alteration

Minor potassic alteration occurs centered about diamond drill hole V6 in the "E" zone. Its depth is limited to perhaps 100 feet (30 m) from the present surface. Its limit is defined by the addition of secondary potassic feldspar as thin cross-cutting veinlets and as coronas about plagioclase grains. The new potassic feldspar (chiefly microcline) is not sericitized along cleavages. Plagioclase is slightly to moderately sericitized as previously described. The quartz content has been enhanced and recrystallized to mostly rounded, spotty, fine grains completely disseminated throughout all minerals. Biotite is not abundant

(1-3%) but appears as secondary, randomly oriented, brown to green laths with traces of chloritization.

Accessory Alteration Effects

Prehnite is occasionally observed as small pods interleaved with biotite within the quartz-sericite zone of alteration. The bent and displaced biotite lamellae surrounding the prehnite pods is indicative of prehnite growth after biotite crystallization. Studies by Field and Rodwell (1968) and by Phillips and Rickwood (1975) suggest that prehnite is of secondary origin forming in response to deuteric or hydrothermal reactions involving plagioclase feldspar. The intercleavage nature of the prehnite pods suggests fluid migration along paths of easy access (Plate IV).

Some opaque minerals within the alteration zones have been formed in response to the release of iron from mafic minerals. Magnetite has formed in excess of pyrite. The alteration opaques are generally distinguishable from hydrothermal additives by their close association to, or inclusion in, biotite that is being chloritized.

The hydrothermal fluids producing the alteration zones have had the net chemical effect of adding F, H, and K in the production or addition of fluorite, sericite, muscovite and new potassic feldspar. There has been a net loss of Ca from plagioclase in the production of carbonate. The An content of plagioclase of Nelson country rock falls in the An_{32}-An_{40} range and within the breccia zones it is An_{20} to An_{35}. Quartz has been enhanced within the breccia fragments and silicification from hydrothermal quartz flooding has produced the matrix cement of the breccia zones.

CHAPTER 7

MINERALIZED ZONES DESCRIPTION

Of the two distinct mineralized breccia zones discovered within the Carmi claim group, part of the "E" zone breccia was discovered by Kennco Explorations (Western) Ltd. The "Lake" zone breccia was discovered by Vestor Explorations Ltd. on the basis of geochemical surveys combined with follow-up prospecting and drilling. The "E" zone breccia has satellite bodies to the northwest, west and south of its boundaries. It appears at present that all breccias are discrete units unconnected at depth.

Two cross-sections (in pocket) A to A' and B to B' show the relationship of intrusive rock units to the breccia zones as modified by faulting. Both breccia zones are elongate in plan and irregular in section. Section B-B' runs through the major bodies of the "E" zone, and section A-A' is a cross-section through the entire plateau from the "Lake" zone to the "E" zone. As can be observed from the sections, the ore-bodies appear as localized bodies within a thin fault-dissected cover of Nelson granodiorite. Only occasionally is the underlying quartz monzonite included in the breccias. Both breccia zones show outward dips with boundaries at depth roughly paralleling the present surface expression. Where the breccias thin at surface (along cross-sections) the boundaries appear to be fault-controlled. However, the north and south boundaries of both breccia zones are not explicable on the basis of

faults, but rather they appear to taper up and thin towards the surface.

In the "E" zone area, the main breccia is possibly open to the east and certainly to the southeast. Limited drilling has been performed to the southeast and percussion drill holes P71 and P72 returned encouraging values below a barren "cap". The small breccia directly south of the "E" zone was discovered only through step-out drilling and has no surface expression. Therefore, the possibility of other "blind" breccias in the area remains high.

With respect to the "Lake" zone, the eastern boundary is very steep and abrupt and appears to be fault-controlled. Drilling to the east of this boundary has failed to locate any extensions. However, as only limited drilling has been done towards the west, the "Lake" zone is considered open in this direction. Possible extensions to the north and southwest can be considered. Slope steepness in these areas makes access difficult but mineralized float occurs over a considerable portion of the slopes.

Within the known breccia zones, fragments range from less than one inch (3 cm) to several feet (0.5 m) across. They probably average 5 inches (12 cm) across. Fragments are angular and show almost no spalling or rounding of corners. The majority of fragments are foliated and have been rotated with respect to one another, even where they are in direct contact with no intervening matrix. A considerable amount of rock, laterally and vertically away from the breccias has been affected by fracturing and/or shearing with associated granulation, but with no rotation of fragments. Some slabby cleavage occurs in the wall rocks of the breccia zones. The bottom boundaries of the breccias has been similarly affected, with well-developed slickensided fracturing.

The breccia matrix consists of milky quartz, rutilated quartz, quartz-feldspar pegmatite and veins of the same mineralogy. The matrix ranges from discrete, irregular patches between large fragments to massive material containing discrete breccia fragments. Volumetrically, milky quartz is the most important matrix followed by quartz-feldspar pegmatite. The amount of matrix material present has a direct influence upon the degree of alteration of fragments. Where small fragments are completely surrounded by matrix, the original textures are completely destroyed. Fractured, unbrecciated rock surrounding the breccia zones has been sealed with quartz and/or pegmatite.

Both the "Lake" and "E" zone breccias are similar with respect to fragments and matrix. However, fragments within the "Lake" zone display more intense alteration. The matrix material is again quartz and quartz-feldspar pegmatite but of a very vuggy nature especially in more massive quartz sections. Miarolitic cavities are lined with euhedral crystals, whose paragenetic sequence will be discussed later.

The geologic boundary between breccia and host rock is not necessarily the cut-off of the Mo mineralization. Although the grade of MoS_2 is significantly higher within the breccias, where the frequency of fracturing of the host rocks is sufficiently high, MoS_2 within quartz veins and fills derived from the breccias does reach economic proportion (i.e., 0.10% MoS_2).

The Nature and Mineralogy of the Primary Mineralization

According to Soregaroli and Sutherland Brown (1976) ... "molybdenite is the only mineral recovered from Canadian porphyry molybdenite deposits, although all contain minor quantities of other minerals, some

of which are of potential economic significance." (p. 428) These minerals include those of tungsten, copper, bismuth, lead, zinc, gold and silver. Pyrite and magnetite are ubiquitous in porphyry molybdenite deposits.

The major portion of the metalliferous mineralization at Carmi is confined to the breccia zones. Molybdenite is the primary mineral of economic significance whilst brannerite must be considered sub-economic at present. Other possible economic minerals include chalcopyrite and sphalerite. In addition, assays have shown the presence of silver, gold, tungsten and rhenium. Apart from the presence of rhenium which is attributable to the molybdenite, the host minerals of the other economic metals are not positively known. Other associated metalliferous minerals include pyrite, magnetite, hematite, ilmenite and rutile in order of decreasing abundance. Rutile has only been identified within vugs of the "Lake" zone and ilmenite is known from trace amounts in the "E" zone.

Non-metallic minerals introduced by the hydrothermal fluids are more varied within the "Lake" zone. They include quartz, potassic feldspar, muscovite, biotite, stilbite (var. stellerite), platey stilbite, two varieties of calcite and fluorite. However, fluorite is not as abundant in the "Lake" zone as it is in the "E" zone, but it does display more variety in the former occurring as purple and green octahedra as well as massive purple fluorite. Most of the above-mentioned minerals occur as euhedral crystals lining miarolitic cavities in vein and matrix quartz. A paragenetic sequence for their occurrence is presented in figure 1.

Non-metallic minerals introduced in the "E" zone include quartz, potassic feldspar, biotite, muscovite, minor calcite and fluorite. No

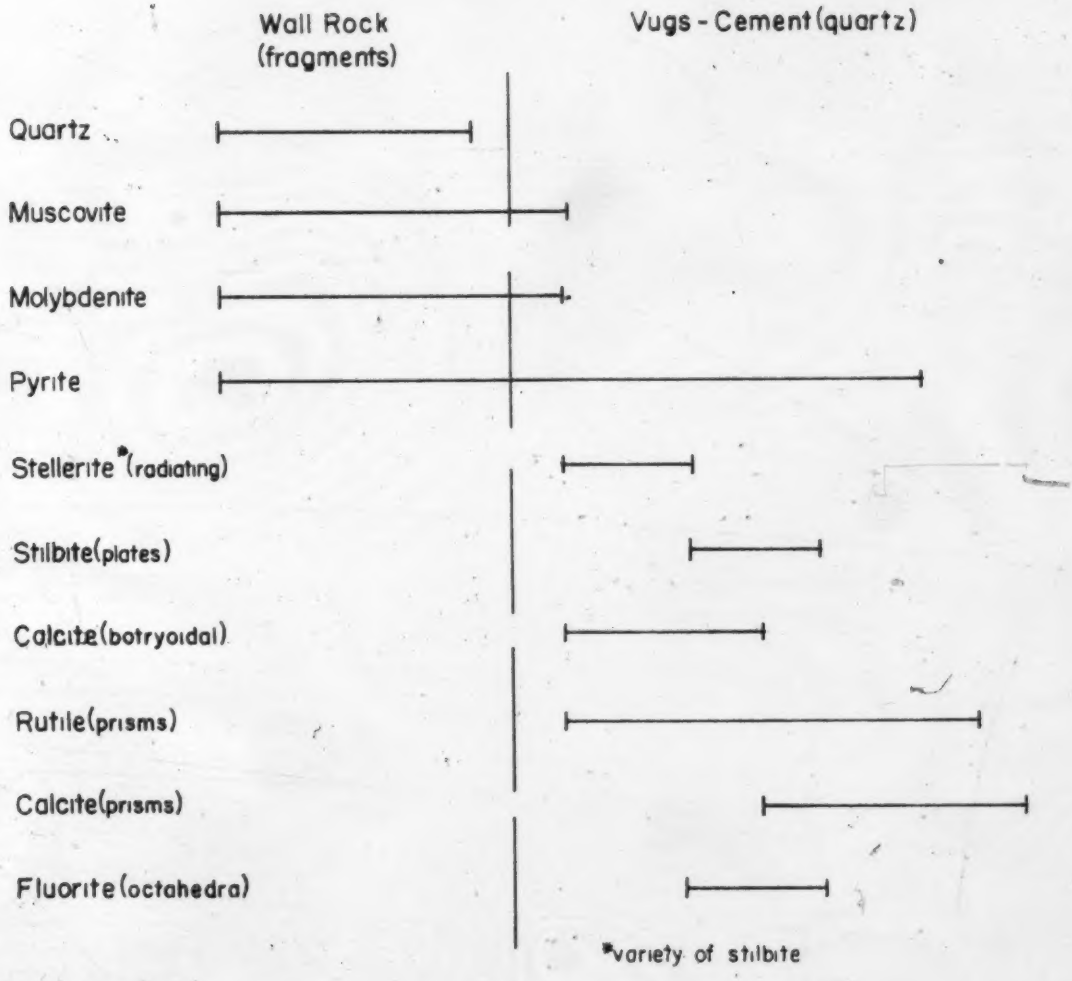


Figure 1. Paragenetic Sequence of Miarolitic Rock Mineralogy.

miarolitic cavities occur in the "E" zone.

The nature of the metalliferous minerals varies between those in breccia fragments and breccia matrix and will be discussed separately. Molybdenite straddles the boundary between fragments and matrix and is also considered separately.

Oxide Minerals

Oxides in Breccia Fragments

Within the "Lake" and "E" zones, oxides are the most abundant opaques associated with the fragments. Magnetite and hematite occur within both zones, with hematite being chiefly confined to the oxidation zone, and at depth, to thin selvages around the occasional magnetite grain. Within the fragments, magnetite averages just over 1% of the rock. It occurs as irregularly distributed, anhedral grains chiefly associated with chlorite, biotite, and to some extent with titanite. It appears to have been formed partly as a result of the chloritization of biotite where it occurs in or close to biotite, and partly as a hydrothermal addition where it is disseminated in recrystallized quartz. The more altered the fragment, without the complete destruction of chlorite, the greater the abundance of magnetite. In some cases it has selectively replaced entire biotite-chlorite grains forming skeletal palimpsest grains (Plate IV).

Oxides in Matrix

Within the predominantely quartzose breccia matrix, magnetite, hematite, brannerite and rutile occur in decreasing order of abundance. Hematite is restricted to some thin reddish stains on fractures and

slickensides and may have mobilized around grain boundaries. Magnetite may constitute up to 3% of the quartz-and quartz-feldspar matrix, but is much more abundant in the former. It occurs as up to 2 mm sized, subhedral to euhedral disseminated grains within the quartz-feldspar pegmatites but within the quartz, it is as large crystalline masses up to 2 cm across or as thin rims around pyrite masses. Occasionally it appears as blebs in pyrite.

The U mineral at Carmi has been identified as brannerite by electron microprobe energy dispersive analysis by Dr. D.G.W. Smith (University of Alberta). Brannerite has so far only been discovered in the quartz matrix of the "E" zone breccia. It occurs as orthorhombic crystals up to 4 mm across and 6 mm long. The crystals are surrounded by radial volume increase cracks in the quartz host.

According to Ferris and Rudd (1971) brannerite is invariably metamict and is thus extremely difficult to identify by x-ray powder camera techniques. Several samples of the Carmi brannerite were examined by powder diffraction techniques and proved to be metamict. Heating of the samples to 1000°C for 1/2 hour resulted in an unidentifiable mixture probably a synthesis of the oxide components of the mineral. The ideal formula of brannerite is UTi_2O_6, but it may contain small proportions of Th, Ca, Fe and of rare earths (Ferris and Rudd 1971). The weight percent of the U component of the Carmi brannerite is 29.3% as determined by chemical analysis. By comparison, the weight percent of U of the Blind River brannerite is 26.5% as determined by microprobe analysis (Ferris and Rudd 1971). An energy dispersive microprobe scan of the Carmi brannerite showed small amounts of Ca ($\sim$3%) and Fe ($\sim$1%). According to Ferris and Rudd (1971) the average Th content of brannerite

is 3% or more, but the Carmi brannerite has no detectable Th. It is anomalous in this respect.

At Carmi, the visible uranium mineralization is not wide-spread on surface (see Geology Map 7), but traverses conducted with a SRAT-SPP2 scintillometer show a considerably larger surface area to be anomalously radioactive. Mean background for the "E" zone (and indeed the whole plateau in general) averages 75 cps. The visible uranium mineralization gives readings of 500 to 700 cps at hip level, and the anomalous area in general falls within a 150 cps isorad line.

Plate II shows radioluxograph photographs and the specimen used from surface sampling of the "E" zone. From drilling an even larger expanse of U mineralization is apparent. Diamond drill holes V7 and V8 intersected sporadic mineralization. Hole V7 intersected 1 foot (0.3 m) of U mineralization at a 30 foot (9 m) depth and 13 feet (4 m) at 211 feet (64 m). Although the radiation was high (1200 cps) in hole V7, no assays were performed. Hole V8 intersected 35 feet (10.6 m) of U mineralization from 305 feet (92.4 m), to 340 feet (103 m) which assayed 0.045% U_3O_8 or 0.9 lb/ton. The radiation was equivalent to that obtained in diamond drill hole V7. It is thus probable that much more brannerite is associated with the molybdenite mineralization at Carmi than has been realized.

Much of the drilling carried out on the "Lake" zone has been percussion drilling. As such, only sludges are obtained and no determinations of U were made. No U mineralization is evident in the two diamond drill holes (V17, V18) from the "Lake" zone.

Source of U Mineralization

Since the brannerite occurs within the hydrothermal quartz matrix of the "E" zone breccia, gamma spectrometric analyses of all rock units was considered as one method of pinpointing the source of the uranium.

Table 3 lists the uranium contents of each rock unit sampled at Carmi. All samples are from surface exposures (except the Valhalla quartz monzonite which was sampled from drill core). Surface oxidation of all samples was considered to be negligible.

Procedure

Each sample was crushed to a fine powder, homogenized, and 1.000 g separated from each and submitted for U determination by delayed neutron activation analysis to Atomic Energy Ltd. of Canada, Ottawa. The equivalent U content (eU) of each sample was also determined by gamma spectrometry in the Department of Geology, University of Alberta. The results are tabulated in Table 3.

The Uppm arithmetic mean of each rock unit is tabulated in Table 4. The two brannerite mineralized samples from the "E" zone were not considered.

Presented in Table 5, are the reported average U contents of various rock types as determined by various authors.

TABLE 3

ANALYSED U CONTENT OF CARMI ROCK UNITS

SAMPLE #	Uppm	eUppm	ROCK UNIT
MK76-1	292.0	297.0	"E" zone breccia
2	3.1	n.d.*	Nelson granodiorite
3	2.2	n.d.	Nelson granodiorite
4	1.6	n.d.	Nelson quartz monzonite
5	3.1	n.d.	Anarchist Group xenolith
6	1.8	n.d.	Anarchist Group schist
7	3.7	n.d.	Valhalla quartz monzonite
8	4.1	4-10	Nelson dike in Anarchist Group
9	3.1	n.d.	Valhalla quartz monzonite
10	323.0	254.0	"E" zone breccia
11	4.7	4-10	"Lake" zone breccia
12	11.2	10.0	Feldspar porphyry dike

*not detectable

The discrepancy between these two results may be due to sample disequilibrium caused by the loss of radiogenic daughter products.

TABLE 4

AVERAGED U CONTENT OF CARMI ROCK UNITS

	Uppm
Anarchist Group metasediments	2.5
Nelson granodiorite	2.65
Valhalla quartz monzonite	3.4
Valhalla feldspar porphyry	11.2
Nelson late-stage dikes	4.1
Nelson quartz monzonite	1.6

TABLE 5

AVERAGE U CONCENTRATIONS OF IGNEOUS ROCKS

	Uppm
Canadian Shield (Shaw 1967)	2.45
Granitic rocks (Heier and Rodgers 1963)	4.75
Granodioritic rocks (Clark et al. 1966)	2.60

A comparison of Tables 4 and 5 shows the Nelson granoriorite to contain expected average U concentrations for granodioritic rocks. Its quartz monzonite derivative is clearly depleted in U, whilst the late-stage derivative dikes cutting the Anarchist Group are clearly enriched in U content. Neither the Nelson quartz monzonite nor the leucocratic dikes constitute large-volume bodies. A comparison of the Valhalla units in Table 4 with the average U content of granitic rocks from Table 5 shows the Valhalla quartz monzonite to be depleted in U and its derivative feldspar porphyry dikes to be considerably enriched in U.

According to Heier and Rodgers (1963), both Th and U concentrations generally increase toward the more silicic, alkalic derivatives during magmatic fractionation. However, the authors also note that the increase in U is often erratic, being strongly affected by secondary processes. It is also possible that U may not be enriched if it is removed by hydrothermal fluids during magmatic evolution.

The U content of the small volume of the Nelson quartz monzonite

could easily be absorbed by the Nelson granodiorite phase during injection of the quartz monzonite. However, the U depletion of a large body such as the Valhalla quartz monzonite must have given rise to a significant amount of U. The enrichment of the Valhalla derived feldspar porphyry dikes is indicative of the mobilization of the U during late-stage events. Since the breccias' quartz cement is a Valhalla derivative it is proposed that the brannerite mineralization was a result of late-stage, U-enriched hydrothermal fluids derived from the Valhalla quartz monzonite.

Sulphide Mineralization

Sulphides in Breccia Fragments

Sulphides (almost entirely pyrite) average under 1% within the breccia fragments. Pyrite appears to be an early-formed mineral, coeval with the host rock. It occurs as 2 mm, disseminated grain remnants that have been partially replaced by silicate minerals. Most of the pyrite shows corrosion and embayment by later formed biotite and especially by muscovite. A small amount of secondary hydrothermal pyrite has been added. Traces of exsolved chalcopyrite are visible in some larger secondary pyrite grains.

Sulphides in Matrix

Pyrite is the predominant opaque constituent of the matrix. Within quartz cement and cross-cutting veins, it may constitute up to 10% of the volume of the rock. The pyrite occurs as aggregates of cubic crystals up to several centimeters across and masses of the same size. The masses are generally quite friable. Magnetite often rims the

outside boundary of the pyrite masses and also occurs as separate blebs within the pyrite. Within the vugs of the "Lake" zone, rare pyritohedra occur, but cubes predominate.

Chalcopyrite is the sole copper mineral identified from the breccia zones. Copper assays rarely exceeded 0.1% and probably average 0.03%. Chalcopyrite is only occasionally recognizable as discrete grains (always in quartz) and usually occurs as blebs within pyrite grains and masses. Oxidation of the chalcopyrite is extremely minimal. Malachite is very rarely seen on surface exposures and is nonexistent at any depth. In polished section, the chalcopyrite blebs in pyrite display extremely irregular outlines and may show thin veinlets emanating from the blebs.

Molybdenite

Molybdenum is the principal element of economic interest at Carmi and in the hypogene deposit occurs exclusively as molybdenite. The mineral occurs entirely encased within breccia fragments as disseminated rosettes (2-5 mm), as thin lamellae (1-2 mm) disseminated on the outside of breccia fragments and as occasional aggregate masses associated with muscovite masses encased in massive milky quartz. Minor disseminated molybdenite occurs in the quartz matrix and quartz veins of the breccia and cutting the Nelson granodiorite respectively, and occasionally as discrete disseminated rosettes within the Valhalla quartz monzonite. The best, consistent grades of molybdenite over long sections are found where one has the disseminated rosette variety occurring in fragments. Much higher-grade molybdenite mineralization (up to 0.5% over 10 feet (3 m)) is that associated with muscovite masses, but

its extent is limited.

The mineralization is obviously a later hydrothermal event as displayed by common cross-cutting relationships. In thin section, molybdenite is seen to be associated particularly with quartz-muscovite and muscovite-mineral boundaries. Molybdenite cuts all of the later minerals with which it is associated. Fluorite may be the exception, as it appears to be contemporaneous with molybdenite and is always associated with better grades of mineralization (Plate III). The degree of alteration of breccia fragments has a direct relationship to the degree of mineralization. Those fragments which display well-developed quartz-sericite alteration show a distinctly higher molybdenite content.

The short sections of massive molybdenite found in quartz veins appear to be always associated with coarse muscovite. The coarse muscovite may represent re-crystallization of an extremely altered fragment or it may be a hydrothermally introduced mineral phase. However, due to the nature and outline of the muscovite clots, plus the fact that muscovite is nearly unknown in the quartz otherwise, the former explanation is more plausible.

Within fractured core intervals, particularly below breccia boundaries, smeared molybdenite has been recognized on fracture planes. Where fractures have been sealed with quartz, molybdenite is often smeared on the contact of quartz with wall rock.

A rough correlation exists between the amount of pyrite and molybdenite grades. Generally, an increase in pyrite content accompanies an increase in molybdenite. Massive pyrite is also associated with muscovite-rich quartz sections.

It is probable that successive pulses of mineralizing fluids are

responsible for the various molybdenite occurrences. Those breccia fragments which are foliated, contain molybdenite rosettes and were probably the first mineralized by molybdenum-bearing fluids percolating along foliation planes to sites of deposition. Successive pulses of mineralizing fluids would increase quartz-sericite alteration of fragments and resulted in massive molybdenite in well-altered fragments and deposition on fragment-quartz contacts. The last stage of mineralization would have been the disseminated variety within the milky quartz matrix. The association of fluorite with much of the molybdenite suggests that fluoride complexes may have played a large role in the Mo transport, as discussed in the section on "Melt Geochemistry".

As mentioned, molybdenite is confined to the breccia zones. It is unknown in any other rock unit except for occasional discrete rosettes in the Valhalla quartz monzonite. Valhalla derived fluids are proposed as the source of the Mo mineralization based upon the preceding information and the association of Mo with U.

Accessory Metalliferous Mineralization

Lead and zinc are known to be anomalously high in the Carmi area on the basis of soil geochemistry, but no assays have been carried out to determine their concentration in the host rocks. No lead-bearing minerals have been identified from either breccia zone and only traces of sphalerite have been identified as 3 mm sized crystals occurring within the quartz matrix of the "E" zone.

Random core samples were run for gold and silver contents one from each of the two breccia zones. From a drill hole just east of the "E" zone breccia, within well-fractured and quartz-veined granodiorite,

a 30 foot (29 m) section of core assayed a trace of gold and 0.12 oz/ton silver. From a drill hole at the eastern edge and within the "Lake" zone, a 135 foot (40 m) section of core assayed 0.01 oz/ton gold and 0.12 oz/ton silver. This latter hole shows the increase in gold content from country rock to breccia. Whilst no change in the silver content was noted, the Beaverdell area as a whole is a known Ag-Pb-Zn camp, silver mineralization is probably carried in the quartz veining as well as the quartz matrix of the breccias. It is presumed that the gold values are attributable to microscopic inclusions in the hydrothermally introduced pyrite of the breccias.

In the section discussing Mo-U melt geochemistry it was noted that in addition to Mo and U, both tungsten and beryllium display similar affinities. Soregaroli and Sutherland Brown (1976) note that scheelite is a minor constituent of most molybdenum porphyries although not in sufficient amounts for it to be considered a possible by-product. At Carmi, only one cored section was checked for tungsten and only trace amounts were reported. This represents a very cursory examination and should not be considered conclusive. No analyses have been conducted for beryllium.

Both cassiterite and bismuth-bearing minerals have been reported from other porphyry molybdenum deposits (Soregaroli and Sutherland Brown 1976, Leary 1970) but their existence is not known at Carmi. However, as cassiterite is often associated with griesen-like alteration, Carmi may represent a possible area due to the often intense quartz-sericite alteration of the host rocks.

Mineralization and Structure

Figure 2 is a diagramatic representation of the periods of mineralization and their relative significance throughout the structural development of the ore-bodies. Stage 2 deformation produced the breccias and the subsequent hydrothermal flooding provided the most significant stage of metallic mineralization. From the information available, it appears that brannerite is restricted to this structural period. It should be noted that pyrite occurs in excess of molybdenite throughout the structural stages.

The development and significance of each of the stages of deformation will be discussed under "Local Structure".

Molybdenite Polytypism

Some recent papers have discussed molybdenite polytypism (Wickman and Smith 1970, Frondel and Wickman 1970, Trail 1963) and more specifically Briton (1974) has discussed polytypism in molybdenite from British Columbian prospects and deposits.

Two crystal class structures are known for molybdenite. The molybdenite polytypes differ only in the way the MoS_2 layers are stacked (Wickman and Smith 1970). The stacking arrangements produce normal hexagonal molybdenite (2H) and the polytypes of two-layer structures termed ($2H_2$) and (2T) and one three-layer rhombohedral polytype (3R) (ibid).

A study made by Frondel and Wickman (1970) of over 100 molybdenite samples from 83 world-wide localities shows that normal 2H molybdenite occurs in 80% of the localities, with 3 localities being exclusively of the 3R polytype and the remainder being a mixture of 2H and 3R in varying proportions. It has been suggested that accessory copper

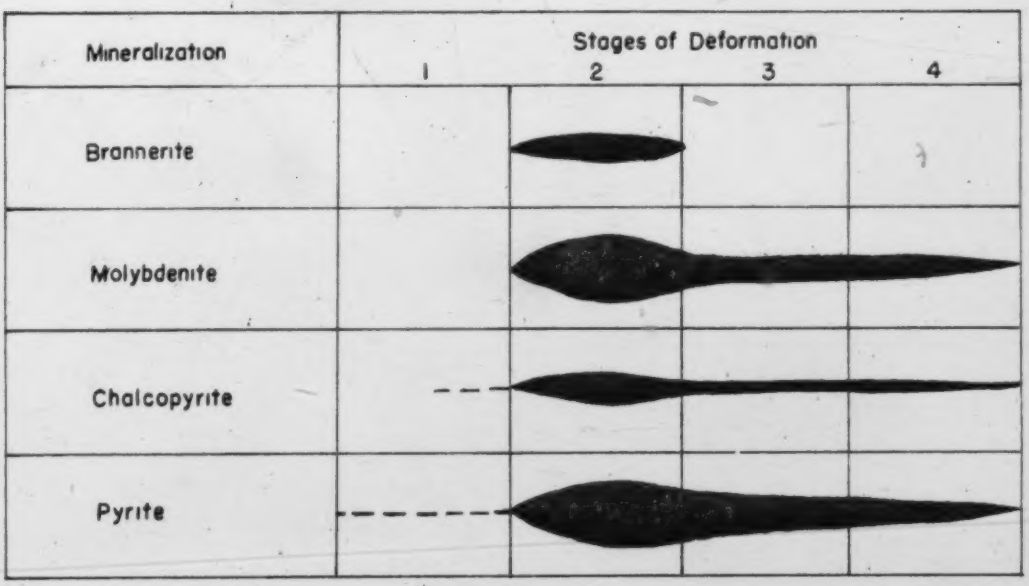


Figure 2. Stages of Hypogene Mineralization Related To Structural Deformation.

mineralization may play a role in the production of the 3R polytype and that where 3R poltypes occur, enrichment of rhenium in molybdenite is noted.

Studies by Briton (1974) on polytypism of B.C. deposits showed 2H molybdenite to be the most common. Boss Mountain was the only producing mine with any of the 3R modification with a ratio of 2H:3R of 4:1.

X-ray diffraction studies of selected molybdenite rosettes and flakes from the Carmi deposit failed to reveal anything other than the normal 2H variety.

Rhenium in Molybdenite

Terada and Osaki (1971) have concluded that rhenium appears to form a solid solution series with molybdenum of ReS_2 (isomorphic) to MoS_2. However, only one complex copper, rhenium, molybdenum sulphide has been found occurring naturally (Soregaroli and Sutherland Brown 1976).

Sutulov (1970) in his studies of rhenium distribution stated that Cu-Mo porphyries contain more rhenium than do Mo porphyries. Vlasov (1968) has studied some Russian molybdenite concentrates and stated that they range from 10 to 500 ppm with an average of 125 ppm Re. Within the British Columbia porphyry Cu-Mo deposits, the Island Copper deposit has the highest known rhenium content of up to 1500 ppm (Alverson 1973). According to Soregaroli and Sutherland Brown (1976) the mean rhenium content of porphyry Mo deposits is 53 ppm.

Evidence gathered by Giles and Schilling (1972) at the Bingham, Questa and B.C. Moly deposits suggests that the rhenium content is a function of the temperature of formation of the deposit. The higher the temperature of formation, the less rhenium is concentrated in molybdenite.

However, the authors also point out that within given blocks of ore of different deposits, the rhenium content does not vary as greatly as individual molybdenite samples might suggest.

Two samples of molybdenite were assayed for rhenium from the Carmi deposit. Both were outcrop samples from the "E" zone. The two assays reported 20 and 145 ppm rhenium. These values fall within the variation ranges previously reported for porphyry molybdenum deposits in B.C. It is not known if the surface oxidation of molybdenite has an effect upon rhenium concentration or depletion, but it is obvious that at a price of $550.00/lb for rhenium that further assays should be performed. It presents an attractive by-product possibility should rhenium-enriched sections of the deposit be found.

CHAPTER 8

WEATHERING AND OXIDATION

The outcrops, where unmineralized, display little weathering below the top several inches. Some minerals have been removed by chemical erosion but iron staining of the outcrop surface is minimal and appears restricted to a thin halo around exposed sulphide grains.

The mineralized outcrops present a vastly different aspect in many area. Leaching of pyrite and the alteration of magnetite to hematite has produced a yellow to dark red-brown coating on the outcrop surfaces. Some sulphide box-work structures have been produced by the complete removal of pyrite. Yellow-orange ferrimolybdite has been produced in minor quantities from the oxidation of molybdenite, but as it often appears similar to goethite it is difficult to accurately determine the extent of molybdenite alteration in the field. Pokalov and Orlov (1974) believe that in the supergene environment, loss of molybdenum is more likely than is retention. Molybdenum loss is directly related to the amount of sulphuric acid formed by the oxidation of pyrite. Sulphuric acid and iron sulphates interact with molybdenite to form ferrimolybdite ($Fe_2(MoO_4)_3 \cdot 7H_2O$) which remains stable within a pH range of 3.2 to 4.7. This suggests that ferrimolybdite will dominate as the MoS_2 weathering product in cool humid climates (Pokalov and Orlov 1974). Most grains of molybdenite and some of brannerite appear visually to be untouched by weathering. However, surface MoS_2 assays performed in the "E" zone ranged between 0.02% and 0.05%. Repeat analyses to determine

equivalent MoS_2 content upgraded the assays to 0.1% to 0.2%. This indicated that molybdenite has been depleted in the surface environment, with the production of ferrimolybdite. Molybdenite has not been lost below this thin weathered rind. This may be the result of recent glaciation to remove much of the previous oxidation zone, and/or the lack of a permeable host rock to facilitate oxidation processes.

The oxidation and removal of uranium has been well documented. Zielinski et al. (1977) concluded from a study of Cenozoic calc-alkaline volcanics that both Mo and U are lost by weathering as a function of climate, rock permeability and bulk composition of the hosts.

From drill information, the average depth of oxidation is 30 feet (9 m) in mineralized zones, but this is largely due to the fractured nature of those areas. Oxidation appears to be confined to joint planes and fractures which in many cases contain pyrite, some of which has been altered to goethite and spread laterally throughout the rock. Thin sections taken within this zone display goethite and hematite stains spreading between grains and as a thin corona around pyrite and magnetite. Rarely, malachite may occur on joint surfaces.

A black, often dendritic manganese hydroxide stain (probably pyrolusite) occurs occasionally on fractures and joints within the mineralized and unmineralized areas.

Geochemical Anomalies

The original interest in the Carmi area resulted from Mo stream-sediment anomalies obtained during a regional geochemical survey. Detailed stream sediment analyses of the drainage system pinpointed the broad plateau above Carmi as the source area, and subsequent prospecting

revealed a molybdenite-bearing breccia.

Within the plateau area, outcrops are scarce, averaging less than 10% of the surface area. Elsewhere, the bedrock is covered by up to 80 feet (24 m) of glacial till, with an average depth of 12 feet (3.6 m). Therefore soil geochemistry was chosen as the best exploration tool to test for Mo mineralization.

An east-west base line completely traversing the plateau was cut with cross-lines at 400 foot (121 m) intervals. Soil samples were taken where possible, from a poorly developed "B" horizon, at 100 foot (30 m) intervals along the grid system. Laboratory analyses of the soil were conducted for Mo, Cu and Zn. Where anomalous concentrations of metals occurred, the specific areas were resampled on a 50 foot (15 m) grid for more accurate control.

All geochemical result available, compiled by the various companies, were calculated for background and threshold values and gave the following result:

TABLE 6

GEOCHEMICAL RESULTS

ELEMENT	#OF SAMPLES	BACKGROUND	THRESHOLD
Mo	1100	5 ppm	12 ppm
Cu	563	21 ppm	50 ppm
Zn	300	170 ppm	300 ppm

The values obtained for the Mo background are at least twice the normal concentrations found in felsic to intermediate rocks, indicating the high Mo content for the area as a whole. The Cu background is less than half the average crustal concentration of felsic rocks. The zinc values are more than twice normal background for felsic rocks and probably reflect the increased Zn-and Pb-rich nature of the area as a whole (as evidenced by the Beaverdell mining camp).

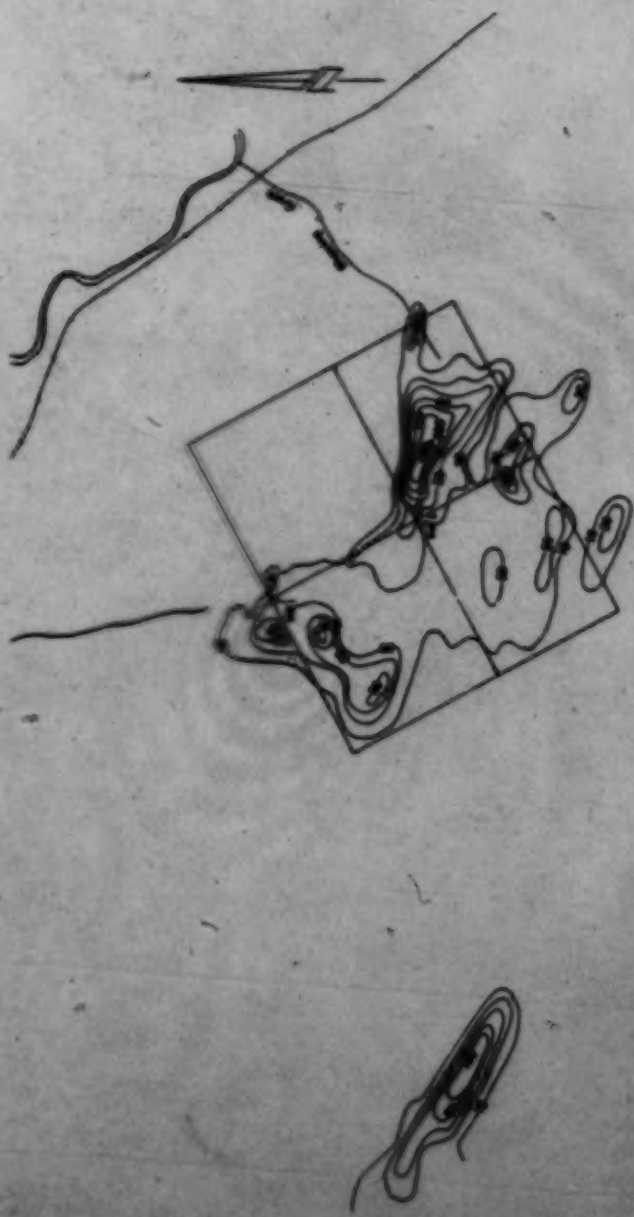
Molybdenum Results

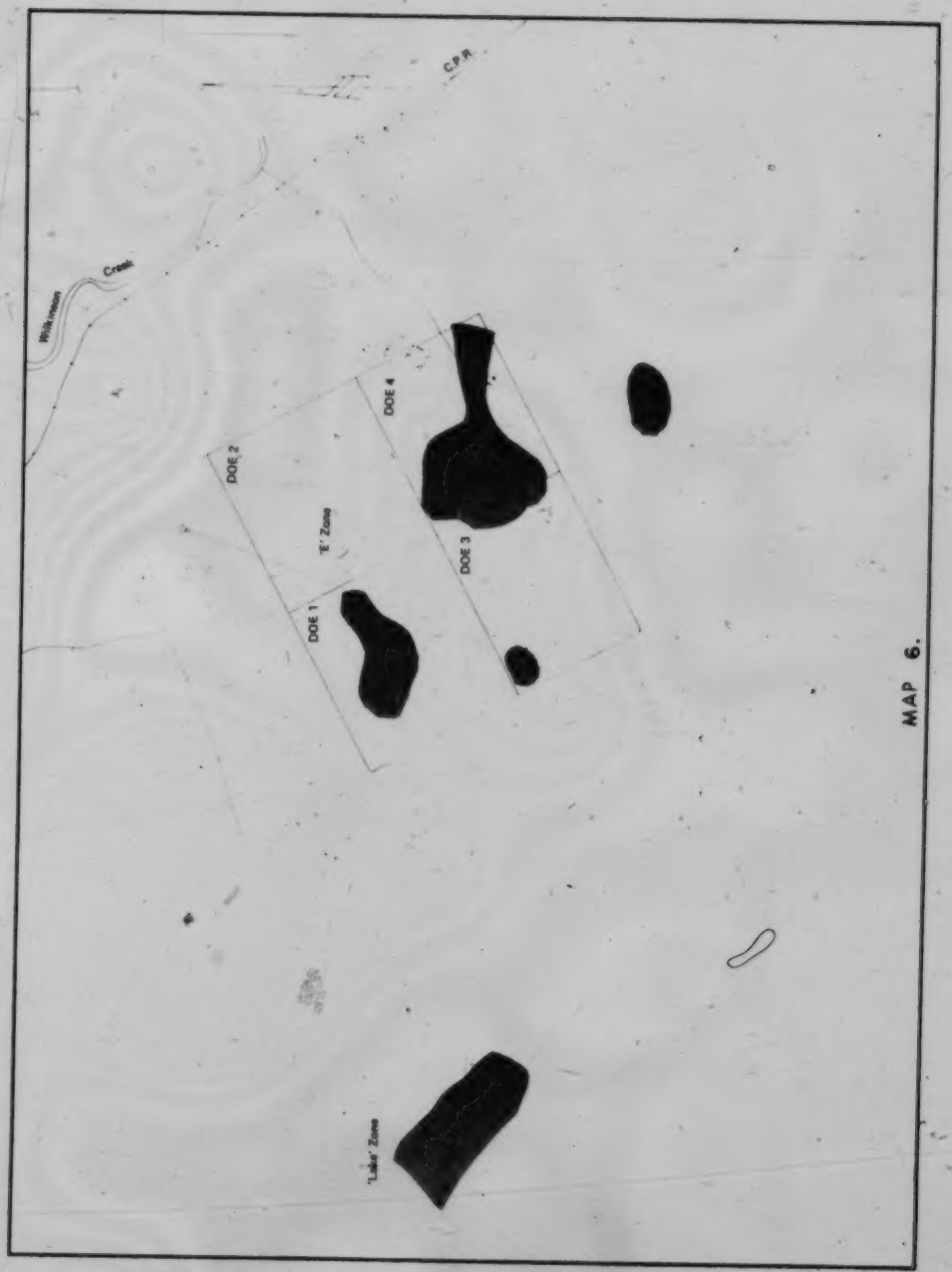
The aqueous chemistry of Mo is complicated and its migration and concentration in the near-surface environment are only barely understood. There is essentially no cationic chemistry and soluble species are mainly sulphides, molybdates or complexes (Boyle 1974). Molybdenum is relatively mobile in alkaline environments and immobile under acid conditions; just the reverse of the case of copper.

The major Mo anomalies found, closely coincide with the known drill-tested mineralized breccias. At the "Lake" zone, Mo in soil values in excess of 100 ppm (20 time background) are localized near the inferred contacts of the breccia with the surrounding granodiorite. The anomaly limits are defined north and south east by this geologic contact, but the extension downslope to the west is in question, as insufficient data points are available.

The inferred surface expression of the "E" zone is completely enclosed within the 10 ppm contour line, where the highest values correspond to the best exposed mineralized outcrops. Values in this area range up to 60 times background.

The linear nature of the anomalies are in part, a reflection of





MAP 6.

downslope drainage and soil creep over a modified glacial surface. Where the anomalies widen, the slope angle increases. It should be noted that the western extension of the "Lake" zone is still open both geochemically and geologically.

Very few outcrops occur over the flat plateau between the two breccia zones, and depth of overburden is not fully known. The absence of interesting values in this area may be a reflection either of a non-mineralized area, or of the lack of exposed breccia, or of perhaps excessive overburden thickness. It is noteworthy that the "blind" breccia with no surface expression just south of the "E" zone shows no geochemical response.

Copper Results

Copper results confirm the association of Cu minerals with those of molybdenum. Copper values range up to 15 times background, but average 10 times background over the best Mo values. These values correspond well with assay results between the two metals which show Cu averaging about 1/10 the Mo values.

The "Lake" zone is only covered by incomplete data for Cu in soil. Some Cu anomalies which do not coincide with those of Mo, demand a closer examination as to their source.

Zinc Results

Zinc geochemical data are available only over the "E" zone. The principal anomaly is coincident with the Mo and Cu "highs", but displays a much wider dispersion pattern, reflecting the high mobility of this metal. A few disseminated grains of sphalerite have been identified from the breccia matrix. The association of zinc with the breccia bodies

suggests that unexplained Zn anomalies demand closer examination.

Geophysical Anomalies

The same system of cut-lines used for the geochemical survey were used for geophysical surveys. I.M.C. Ltd., Granby Ltd., and Craigmont Ltd., have all performed either induced polarization (I.P.) and resistivity or self potential (S.P.) surveys to try and delineate mineralized sectors.

With respect to S.P. surveys, it is Dobrin's (1960) opinion that the self potential method was useful only to depths of 100 feet from surface. Since S.P. surveys depend upon electrical potential differences between oxidized and non-oxidized ore, the lack of a sufficient zone of oxidation at Carmi would clearly indicate that it would be unlikely for this method to succeed.

The greatest and most successful application of the I.P. method has been in the search for disseminated basemetal deposits of less than 20% by volume. Sulphide mineralization of as little as 1% by volume has only met with limited success and these were under "proper" geological conditions (company report, Phoenix Geophysics Ltd.).

Numerous anomalies have been outlined by the I.P. surveys not all of which have been test drilled. Both the "Lake" and "E" zone display anomalous high resistivity centers. However, this is presumably strictly on the basis of associated pyrite within the breccias. Molybdenite is an extremely poor conductor and does not contribute to the I.P. effect. Where breccia zones are not pyrite-rich, resistivities are lower. If it can be determined at Carmi that a change from high to low resistivity is indicative of a change of rock type, or structural deformation (i.e.,

brecciation) then I.P. surveys might be useful to indicate breccia zone extensions.

Not all indicated geophysical anomalies have been investigated as yet. Unfortunately, those anomalies tested have been percussion drilled and the sludges assayed. Molybdenite values have been considered uninteresting but no explanations for the anomalies can be proposed without having observed the rocks. At least one diamond drill hole in each geophysical anomaly would be wise to determine if the source of the anomaly is a result of hydrothermal rock alteration or of structural deformation. Either case would provide leads to the possible discovery of new mineralized areas.

CHAPTER 9

BRECCIA GENESIS

Breccia Characteristics

Neither the "E" nor the "Lake" zone breccia bodies are well exposed. Most of the information concerning these units was obtained from diamond drill core analyses. The breccia zones are elongate in plan and irregular in section (see cross-sections). From limited drill information it appears that the breccias of the "E" zone are unconnected and are discrete entities. They are related to the contact zone of the Nelson and Valhalla intrusions at depth and perhaps to the Nelson and Anarchist Group contact at their upper limit. This latter association has everywhere been removed by erosion. However, in addition to plutonic rock units within the breccias, occasional xenoliths of metasedimentary rocks are found, probably derived from the overlying Anarchist Group.

The contact zone between breccia and Nelson or Valhalla intrusions is often slickensided or consists of a narrow gouge zone. The enclosing rock may be fractured for several hundred feet beyond the breccia boundary particularly the Valhalla unit at depth. Slabby cleavage is occasionally observed in outcrop adjacent to breccia zones.

Theoretical Models

The generation of breccia bodies associated with porphyry-type ore deposits has been the subject of much discussion. The most common breccias are breccia pipes whose vertical dimensions are many times

greater than the horizontal dimensions and whose attitude is quasi-vertical. Such pipes are elliptical or nearly circular in outline (Simons 1964). They are referred to as "intrusive breccias" and have been well documented by Gilmour (1977). The generation of such a pipe is associated with intrusive activity at depth, whose hydrothermal fluids percolated upward to brecciate either by solution removal or by diatreme activity, usually resulting in the mineralization of the fragments (Simons 1964).

Lorens et al. (197) whose discussion of diatreme development includes both vented and "blind" diatremes, stated that breccia pipes are formed by fluidized gas-solid systems rising along fractures and joints and that channel enlargement occurs through spalling and slumping of the walls. The system propagates itself through successive downward release of pressure. Therefore the system must first vent into a lower pressure environment. The diatremic system often results in a rough zonal arrangement of country rock from higher levels occurring below their stratigraphic limit on the outer boundaries of the pipe and rock from below carried above their natural limit in the central part of the pipe. The venting and fluidization of the pipe results in rounded fragments due to abrasion. Lorens et al. (197) state that "blind" diatremes do not reach the surface as breccias. But it seems improbable that the fluidization process necessary to produce diatremes could result without a continuous release of pressure. It seems more likely that even "blind" diatremes must have some surface expression, even if it is only a minor system of quartz veins (Perry 1961).

At Carmi the breccias are considerably larger in horizontal than in vertical extent. The breccias do not taper downwards and there is a

definite lack of any zonal arrangement of the fragments, which are only rarely rounded. Thus Carmi cannot be considered to have been formed as an intrusive breccia in the mode of a diatreme.

An alternate theory of breccia development which lends itself to the Carmi situation was proposed by Norton and Cathles (1973). The authors suggest that breccia pipes may be formed by the collapse of overlying rock into a void caused by the rise of magmatic waters to the top of a magma chamber. They believe that the rounding of many fragments is in fact a post-breccia phenomenon associated with hydrothermal corrosion. Although in their discussion (Norton and Cathles 1973) the authors are concerned with the explanation of breccia pipes (characteristics as described above) the mechanism of breccia development that they describe does not preclude any particular breccia body shape.

Breccia Void Generation

The formation of any breccia body involves a problem of volumes. To accommodate the increased volume of a breccia, two concepts are possible. Either rock must be removed, perhaps by venting, or rock may collapse into an existing void. The creation of a void by diatremic activity results in milled fragments. The collapse into a pre-existing void by surrounding rock does not have to result in either a specific breccia shape or the milling of the fragments.

Norton and Cathles (1973) considered the volume of available magma and the volume of available exsolved water to explain the generation of a vapor void at the roof of a cooling pluton. The collapse of rock surrounding the vapor phase into the void may produce a breccia body whose ultimate size and shape are determined only by the volume of the

vapor void and the caving characteristics of the surrounding host. The system may or may not eventually vent.

The following calculations are based upon the known maximum outlines of the Carmi breccias and a proposed extent of the underlying Valhalla quartz monzonite.

	Lake zone breccia	"E" zone breccia
length	650 ft (198 m)	1400 ft (426 m)
width	300 ft (91 m)	750 ft (228 m)
depth	500 ft (152 m)	350 ft (107 m)
volume:	2.7×10^6 m^3	1.04×10^7 m^3

total volume: 1.3×10^7 m^3

Valhalla intrusive

length 6000 ft (1800 m)
width 4000 ft (1200 m)
depth 4000 ft (1200 m)

total volume: 2.6×10^9 m^3

volume of Valhalla times density of 2.7 gm/cm^3 = 7.02×10^{12} kg,
assuming a minimum of 2 wt% H_2O*, weight of water = 1.4×10^{11} kg,
volume of H_2O at 800°C and 0.5 kbars = 9.1 cm^3/gm*,
total volume of contained H_2O = 1.27×10^9m^3
$\therefore$ H_2O void available = 1.27×10^9m^3
breccia volume present = 1.30×10^7m^3

*from Burnham (1967)

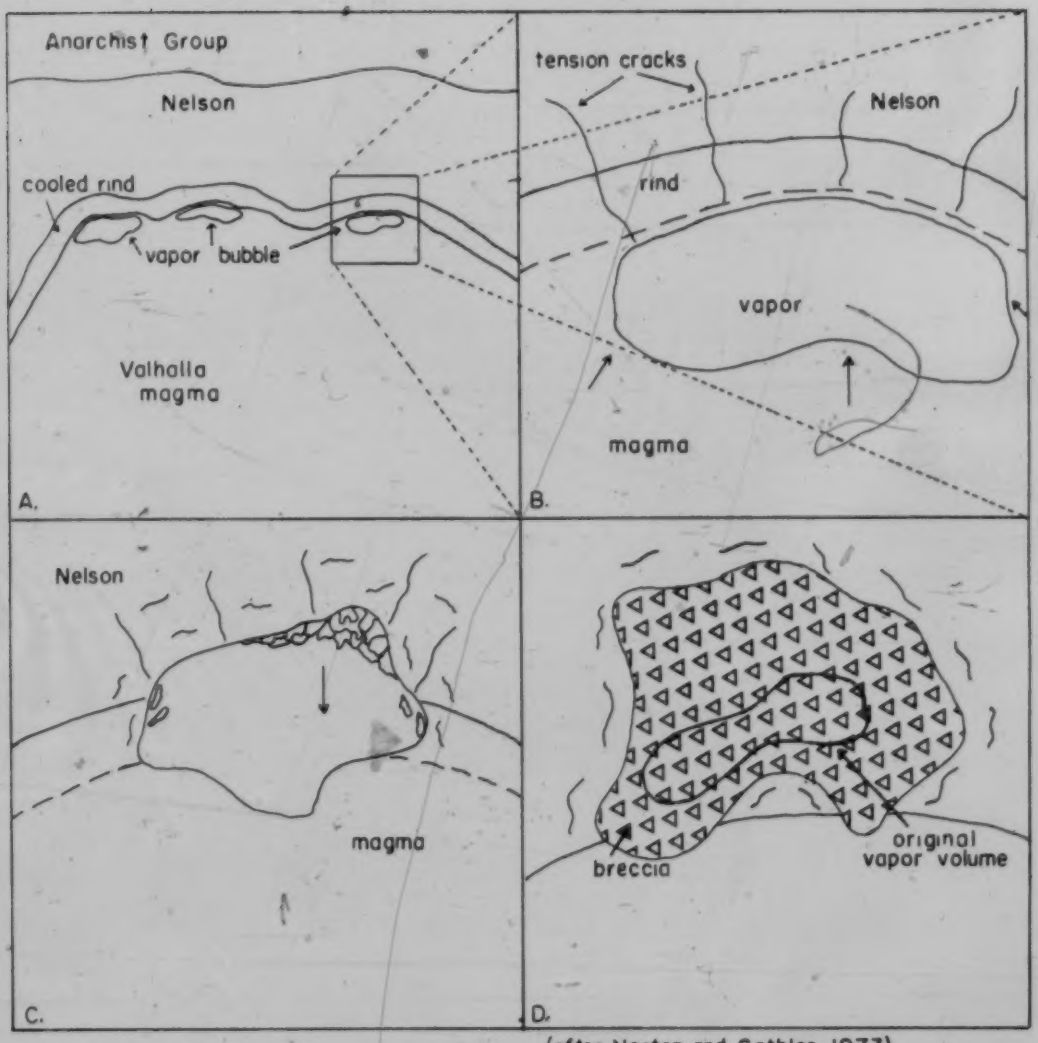
The choice of 2 wt% H_2O is a minimum figure from Burnham (1967) who indicates that a quartz monzonite magma may contain between 2 and 6 wt% H_2O.

The choice of 0.5 kbars of pressure (which is a sub-volcanic environment) was used based upon the slightly prophyritic nature of the Valhalla quartz monzonite, plus fluid inclusion evidence presented later which indicates some venting of the system. The resultant calculations indcate that there was approximately 100 times more void space available than there is breccia present.

Figure 3 describes the proposed mechanism for the evolution of the Carmi breccia bodies. As can be seen from the diagram, the breccia generated is larger than the pre-existing void space. The propagation of the Carmi breccia was upward into the Nelson cover. The implication that the breccia was many times its present vertical dimension is evidenced by the occasional Anarchist Group breccia fragment. Norton and Cathles (1973) made note of the Lovers Lane breccia (Santa Rita, New Mexico) generated by such a system that is found predominantly in the sedimentary host rocks of the Santa Rita stock.

Block caving and stoping of the overlying rock will take place when the lithostatic pressure exceeds hydrostatic pressure due to piercement of the bubble through the cover. Since the Carmi breccias occur nearly entirely within the Nelson granodiorite, it seems likely that brecciation was propagated upward through a system of tension fractures in the Nelson and Anarchist rocks from upwardly directed doming pressures.

The breccias then became major hydrothermal channelways due to their inherent porosity. The intense quartz-sericite alteration, and vuggy nature of the "Lake" zone breccia indicates that this was probably a major conduit in the hydrothermal plumbing system (Neuerburg 1974). This hypothesis is consistent with Burnham's (1967) observation that miarolitic cavities will occur in deformable rock to accommodate the



(after Norton and Cathles 1973)

A. Exsolved magmatic water is trapped beneath cooled outer rind of intrusion.

B. Hydrostatic pressure fractures rind and vapor bubble begins to break through.

C. Resulting decrease in hydrostatic pressure starts brecciation by cavity filling through stoping and sheet fracturing.

D. Breccia body grows upward until cavity is filled and thus can support weight of surrounding rock.

Figure 3. Generation of the Carmi Breccias.

increased volume of an accumulating aqueous phase of a cooling magma.

Fluid Inclusion Evidence

Plate VI shows fluid inclusions from the quartz matrix of the breccias. The heterogenous nature of the inclusions and the presence of liquid H_2O, CO_2 and CO_2 vapor indicate that the system boiled, or effervesced. The boiling or effervescence is the result of pressure release and therefore indicates venting of the Carmi deposit. However, since the breccia fragments are not milled, venting cannot have been of a particularly explosive nature.

Conclusion

The collapse of the Nelson rocks into the vapor void resulted in the development of slabby cleavage near the breccia zones. The hydrothermal solutions percolating through the breccias gave rise to the Mo and U mineralization and quartz-sericite and minor potassic alteration features. Some breccia fragments which do show some minor corner-rounding have been corroded by hydrothermal solutions as a post-breccia phenomenon.

Since more void space was available than breccia present, two alternate explanations are possible. Either the breccias developed have been removed by erosion, or not all breccias have as yet been discovered. Since Mo and U are zoned, and only the bottom of the U mineralization is present, it is obvious that much of the original breccia volume has been removed. However, since "blind" breccias have been discovered by drilling, it seems probable that at least some other breccias do exist. An undulating contact between the Valhalla and Nelson rocks could give rise to individual pockets of exsolved vapor resulting in discrete breccia bodies.

Local Structure

The structural history of the Carmi deposit is presented below. The interpretation is based upon the cross-cutting relationships of the structural elements involved.

TABLE 7

CARMI STRUCTURAL HISTORY

stage 1:	foliation and minor shearing of the Nelson intrusion by regional orogenic events including initiation of the West Kettle River shear zone.
stage 2:	intrusion of the Valhalla quartz monzonite causing fracturing and shearing and brecciation of the overlying Nelson. Hydrothermal activity.
stage 3:	emplacement of inter-mineral feldspar porphyry dikes contemporaneous with mineralizing hydrothermal events.
stage 4:	development of horst and graben fault system and last pulse of hydrothermal event.

Stage 1 Deformation

Foliation of the Nelson granodiorite was a pre-Valhalla event, as evidenced by the massive nature of the quartz monzonite in drill core. Foliation was a result of the alignment of mafic minerals. Foliation trends are roughly east-west and display a variety of dips from north to south. The east-west strike is indicative of a north-south compressional field. Some evidence of shearing is present on slickensided joint surfaces.

Stage 2 Deformation

The intrusion of the Valhalla quartz monzonite resulted in the development of fractures and breccia zones in the Nelson granodiorite as described in the section on "Breccia Genesis". Vertically directed doming pressures reactivated some earlier-formed Nelson joints. Mineralizing hydrothermal fluids derived from the Valhalla percolated through the formed breccias.

Stage 3 Deformation

Inter-mineral feldspar porphyry dikes were emplaced in steeply dipping fractures. Only 3 such dikes are known of which 2 are associated with breccia zones. The well-exposed "Lake" zone dike varies in width from 10 to 50 feet (3 to 15 m).

The dikes cut mineralized breccia but are not in themselves mineralized by molybdenite. They are however, brecciated where they are cut by later faults. The infilling quartz cement is mineralized with pyrite and minor molybdenite. No incorporated Nelson breccia fragments have been observed in the dikes.

Stage 4 Deformation

The final structural deformation at Carmi involved the development of the small-scale horst and graben fault system. The system of faults was interpreted from air photographs and diamond drill intersection. Overburden obscures most surface expressions.

The faults all show normal movements. It is proposed that contraction of the Valhalla through consolidation or removal of magma at depth caused the subsidence that gave rise to the faulting. These movements gave rise to a final molybdenite-poor hydrothermal event. Some

smeared molybdenite in quartz veins along the faults indicates more than one period of movement.

Age Dating of the Mineralizing Event

Since the U mineralization at Carmi occurs chiefly within the quartz matrix material of the "E" zone breccia, U-Pb age dating was chosen as a method of determining the age of the hydrothermal event and the probable age of the Valhalla quartz monzonite. The deformation and plutonic emplacements associated with the Shuswap metamorphic complex have been dated by K-Ar dating of mafic minerals and by stratigraphic relationships exposed and have been discussed previously. To date, however, no U-Pb age dates have been published. Due to the nature of K-Ar age dates with respect to metamorphic events and to the loss of radiogenic daughter products, U-Pb age dating must be considered a more reliable method.

U-Pb dating of a brannerite crystal separated from the quartz matrix of the "E" zone was performed at the University of Alberta Geology Department by Dr. H. Baadsgaard with the assistance of G. Bloy. Chemical analysis indicated that the sample crystal contained 29.26% U. Analysis provided the following information:

Pb^{206}/U^{238} : 0.009659 equivalent to 62 my($\pm$1)

Pb^{207}/U^{235} : 0.06252 equivalent to 62 my($\pm$4)

Pb^{207}/Pb^{206} : 0.04692 equivalent to 45 my*

*considered inaccurate

Since the U-Pb age dates are the same, the sample can be considered concordant with respect to the loss of daughter products. The Pb-Pb

age date is considered inaccurate owing to the young age of the brannerite. (That is, it is felt that the production of Pb^{207} over a 60 my period is small.) Since the original sample weight was also quite small (0.0145 g) errors in the estimation of Pb^{207} produce large errors in the Pb^{207}/Pb^{206} ratio.

The date of 62 $\pm$ 1 my is considered the age of the mineralizing event at Carmi and represents the stage of hydrothermal activity associated with the intrusion of the underlying Valhalla quartz monzonite. The age also corresponds to the proposed last major phase of penetrative deformation in the Shuswap complex by the Columbian Orogeny (Reesor 1965).

CHAPTER 10

ECONOMICS AND FEASIBILITY OF Mo AND U

The economics and feasibility of any metalliferous deposit are intimately associated with mineral supply and demand climates. Mineral supply and demand in turn are complex fields involving national and international economics and trade policies. However, assessments and predictions are possible over the short term for materials whose importance is not linked to monetary problems.

Molybdenum

Molybdenum has found an increased market as an alloying agent to impart hardness, strength and corrosion-resistance to steel, cast-iron and non-ferrous metals (Kuklis 1975). It is also used in lubricants and in paints and pigments as a coloring agent. More than 90% of all molybdenum production goes to the steel and alloy industries. Over the years it has replaced the singular use of Cr, Mn, Ni and W and may be used alone or in conjunction with the aforementioned metals.

The U.S. Bureau of Mines (Kuklis 1975) has identified world molybdenum reserves as 13 billion pounds of which the U.S.A. has 1/2 and Canada 1/6. Indicated resources are estimated at 63 billion pounds worldwide. However, much of the resource information is sketchy and from unidentified sources. No minable grade estimations from future resources are possible over the long term due to metal price increases and capital costs.

The U.S. Bureau of Mines (Kuklis 1975) forecasts a 4.5% per year increase in demand for molybdenum to the year 2000. In 1976, U.S. molybdenum production totalled 113 million pounds with Canada in second place producing 31 million pounds. These figures amounted to a 7% production increase over 1975 figures (Northern Miner, Feb. 3 1977). The supply situation remained inadequate to meet existing demand which rose to 11% over 1975 (World Mining Review 1977). The discrepancy between supply and demand depleted producer inventories and completely absorbed the sellout of the U.S. strategic stockpile of molybdenum. The net result has been a series of price increases by the Climax Molybdenum Corporation to a present price level of $US4.01/lb molybdenum in an 86-95% MoS_2 concentrate.

The supply-demand situation fares well for increased molybdenum prices. During successive price increases for the metal, its major market, the steel industry was and is at present, suffering a recession. The expected recovery of the steel industry will put greater demands upon molybdenum production and undoubtedly result in increased exploration and development expenditures. It is estimated by the U.S. Bureau of Mines that capital investments are in the range of $4000.00 to $8000.00 per ton of molybdenum produced with a discovery to production lag for underground and open pit mines of 7 years and 3 years respectively.

Uranium

The demand for uranium has experienced a phenomenal growth over the last several years. The present price of $US43.00/lb U_3O_8 is in part a reflection of the increased cost and inefficiency of fossil fuels and projected world fuel demands. The main problem facing the uranium

industry is the need for accurate forecasts of future needs. Predictions of uranium consumption are complex and continually being revised

Statistics from Woodmansee (1975) show a projected uranium growth rate of 9% for the U.S.A. and 16% for the rest of the world to the year 2000. He predicts that by 1985, cumulative world consumption may be 650,000 tons of U_3O_8. By 1985, it is estimated that the total world uranium consumption will be about 95,000 tons of U_3O_8 but that production capabilities may be in the range of 110,000 tons (Financial Post Jan. 28 1978). From these figures it appears obvious that the nuclear energy industry will show a slow growth in the future. It is also possible that should a number of known low-grade uranium deposits be exploited, that the price of U_3O_8 will decrease.

CHAPTER 11

GENERAL SUMMARY AND CONCLUSIONS

Study of the Carmi Mo-(U) deposit has resulted in the recognition of diadochy between Mo and U in this deposit, analagous with that recorded in other igneous deposits containing Mo and U. Hypogene Mo and U zoning is also apparent at Carmi, however, only a minor part of the U mineralization has survived weathering and erosion.

To date, two molybdenite-mineralized breccia zones have been discovered, namely the "E" zone and the "Lake" zone. Drill-indicated reserves show the combined tonnage and grade of these zones to be 38 million tons (34.5 million tonnes) of 0.151% MoS_2. Coeval U mineralization, represented by brannerite, is at present sub-economic.

Petrologic investigations indicate that the 62 my old Valhalla quartz monzonite and its derivatives, intruded and brecciated an older foliated Nelson granodiorite intrusion. It is believed that the Valhalla intrusion was coeval with the final stage of penetrative deformation in the Columbian Orogeny.

The breccia bodies are composed of angular, rotated fragments of Nelson granodiorite, cemented by quartz and/or quartz-feldspar pegmatite. Molybdenite occurs as rosettes, disseminated lamellae and massive aggregates. Brannerite is restricted to a small portion of the "E" zone breccia, where it occurs within the breccia quartz matrix. Both U and Mo mineralization are proposed to have been derived from the Valhalla intrusion and

transported by hydrothermal fluids, probably as fluoride complexes. The hydrothermal fluids produced characteristic porphyry-type alteration within the breccias; including pervasive propylitic alteration, quartz-sericite alteration and minor potassic alteration.

The generation of the breccia bodies is believed to be a result of the collapse of the overlying Nelson granodiorite, into vapor voids formed at the contact of the Nelson with the intruded Valhalla quartz monzonite. The volume of the exsolved magmatic water was calculated to be 100 times larger than the volume of the known breccias. Therefore, either much of the pre-existing volume of the breccias may have been removed by erosion and/or some undiscovered breccias are present.

The structural development of the Carmi deposit may be divided into 4 stages involving; regional foliation events, intrusion of the Valhalla and brecciation, emplacement of feldspar porphyry dikes and final faulting of the ore-bodies. All local events have associated stages of hydrothermal activity.

The Carmi deposit represents one of the major undeveloped molybdenum prospects in Western Canada. The possibility of discovering further reserves remains very high. Further, the recognized association of U with Mo in such environments should stimulate exploration interest in such dual commodity resources.

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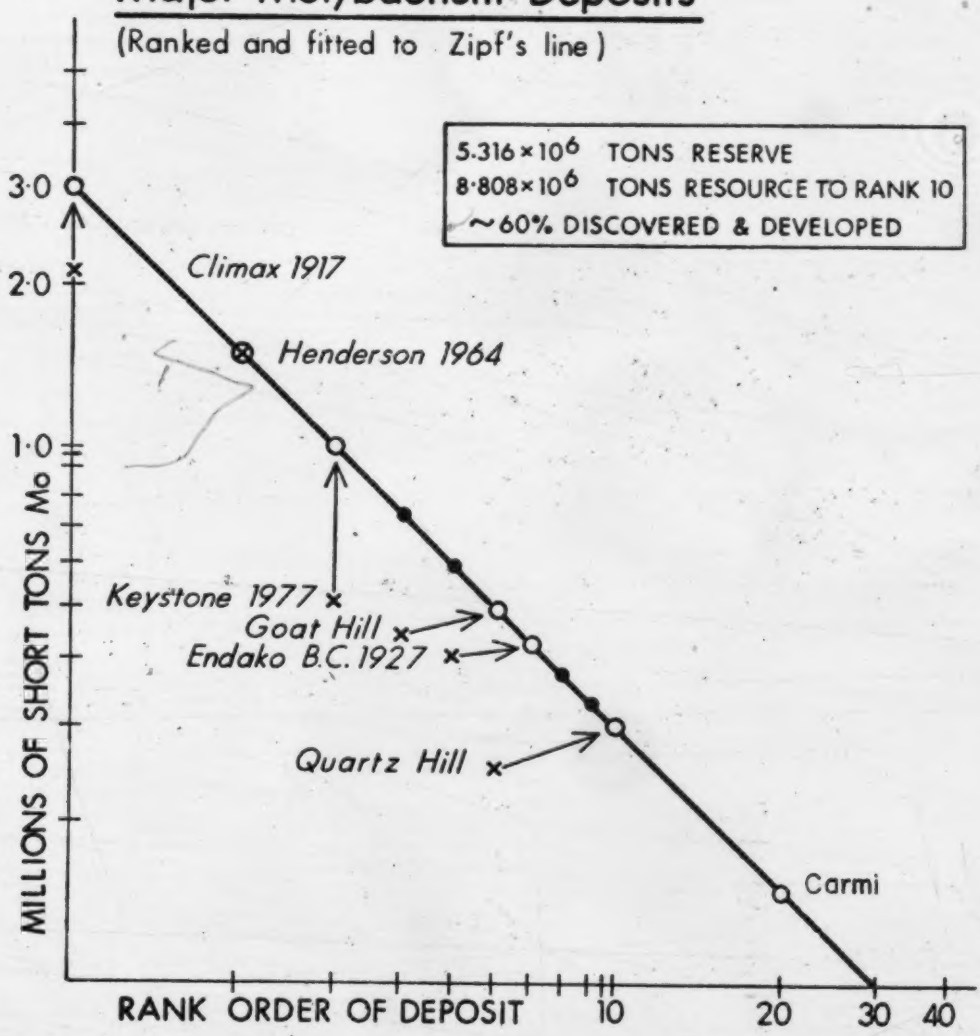
APPENDIX I

North America

Major Molybdenum Deposits

(Ranked and fitted to Zipf's line)



(after Folinsbee 1978, unpublished report)

APPENDIX II

Drill Procedures

Since molybdenite is a soft flaky mineral with excellent flotation characteristics, it is easily flushed by water during drill operations. Initial drilling by I.M.C. of the Carmi showing showed inconsistencies between mineralized surface exposures and assay results from drill core. Assay results were considerably lower in cored sections.

Vestor Explorations Ltd. significantly improved molybdenite recovery by collecting and assaying the cuttings and sludge returned from drilling operations. A "Thompson Sludge Cutter" collected all drill returns and cut 1/20 of the total to be saved for assay purposes. A fine gauze bag permitted water to pass through but retained even small particle sizes. Sludge samples were collected along even 5 and 10 foot intervals to correspond to the same sections of core that were split for assay.

For BQ wireline drill equipment, the outside hole diameter is $2\frac{23}{64}$ inches while the core diameter is $1\frac{7}{16}$ inches. Therefore the returned sludge represents 62.88% of the volume of the hole and core volume is 37.12%. A weighted assay is obtained by using the formula presented below:

$$\frac{(\text{sludge assay} \times \text{sludge vol.} + \text{core assay} \times \text{core vol.})}{100}$$

After the initial diamond drill holes had determined the nature of the geology and mineralization, further drilling in the known zones was

done by percussion drilling. This method returns cuttings only and is cheaper per foot and means only a single assay per interval rather than two.

APPENDIX III

CARMI DRILL HOLE RESULTS

Hole No.	Depth (m)	Intersection	Length (m)	Assay ($\%MoS_2$)
DDH 1-5		no significant mineralization		
DDH 6	126.5	3.3 - 115.8	112.5	0.12
DDH 7	106.7	0 - 97.5	97.5	0.18
DDH 8	114.3	9 - 105	96	0.16
DDH 9	138	1.8 - 126.5	124.7	0.08
DDH 10	111	14 - 105	91	0.12
DDH 11	83	3.6 - 65.6	62	0.23
DDH 12	135	2 - 125	123	0.20
DDH 13	81	7.6 - 22.9	15.3	0.04
DDH 14	85	very low grade		
DDH 15	62	11.8 - 42.4	30.6	0.20
DDH 16	73	4.6 - 36.6	32	0.05
DDH 17	169	1 - 41.2	40	0.15
DDH 18	189	0 - 174	174	0.14
DDH 19	207	30 - 42.7	12.7	0.16
		107 - 134	27	0.12
77-21-26		no significant mineralization		
VP 1	30	1 - 30	29	0.08
VP 2&3		no significant mineralization		

Hole No.	Depth (m)	Intersection	Length (m)	Assay ($\%MoS_2$)
VP 4	91	12.2 - 21.3	9.1	0.06
VP 5	91	no significant mineralization		
VP 6	91	9 - 39.6	30.6	0.04
VP 7	30	1.8 - 30	28.2	0.10
VP 8		no significant mineralization		
P 9	122	15.8 - 122	106.2	0.06
P 10		no significant mineralization		
P 11	110	79.3 - 97.6	18.3	0.11
P 12		no significant mineralization		
P 13	122	9 - 122	110	0.15
P 14-17		no significant mineralization		
P 18	122	12 - 122	110	0.06
P 19-21		no significant mineralization		
P 22	122	6 - 122	116	0.03
P 23	107	30 - 107	77	0.16
P 24	107	24.4 - 60.9	36.5	0.03
P 25&26		no significant mineralization		
P 27	119	85.4 - 119	33.6	0.03
P 28		no significant mineralization		
P 29	107	6 - 107	101	0.06
P 30	107	0 - 107	107	0.03
P 31	122	61 - 91	30	0.03
P 32	46	6 - 46	40	0.17
P 33	122	6 - 122	116	0.18

Hole No.	Depth (m)	Intersection	Length (m)	Assay ($\%MoS_2$)
P 34	116	3 - 115.8	112.8	0.03
P 35	122	9 - 122	113	0.06
P 36	114	6 - 114.3	108.3	0.03
P 37	122	6 - 122	116	0.23
P 38	122	12 - 122	110	0.09
P 39	122	9 - 122	113	0.05
P 40	122	0 - 122	122	0.03
P 41	91	12 - 91	79	0.08
P 42	91	24.4 - 91	66.6	0.03
P 43	91	12 - 91	79	0.07
P 44	106.7	30 - 106.7	76	0.04
P 45	91	48.8 - 91	42.2	0.03
P 46	91	very low grade		
P 47	91	12 - 24.4 42.7 - 48.8	12.4 6.1	0.04 0.05
P 48-70		no significant mineralization		
P 71	91	71.6 - 91	19.4	0.07
P 72	91	36.6 - 91	54.4	0.06

PLATE I

1. A boulder of the "E" zone breccia showing a range of fragment sizes. Note the development of later white quartz veins cutting both fragments and quartz matrix.

2. A boulder of the "Lake" zone breccia showing intense quartz-sericite alteration almost completely masking the fragments.

3. Outcrop of the "E" zone breccia which here shows moderate quartz-sericite alteration. Note the variance in size and the angular nature of the fragments. The foliation in the fragments has not been destroyed.

4. A less intensely altered "Lake" zone breccia block with rutilated and milky quartz cement. Some small miarolitic cavities are visible in the lower block.

PLATE I

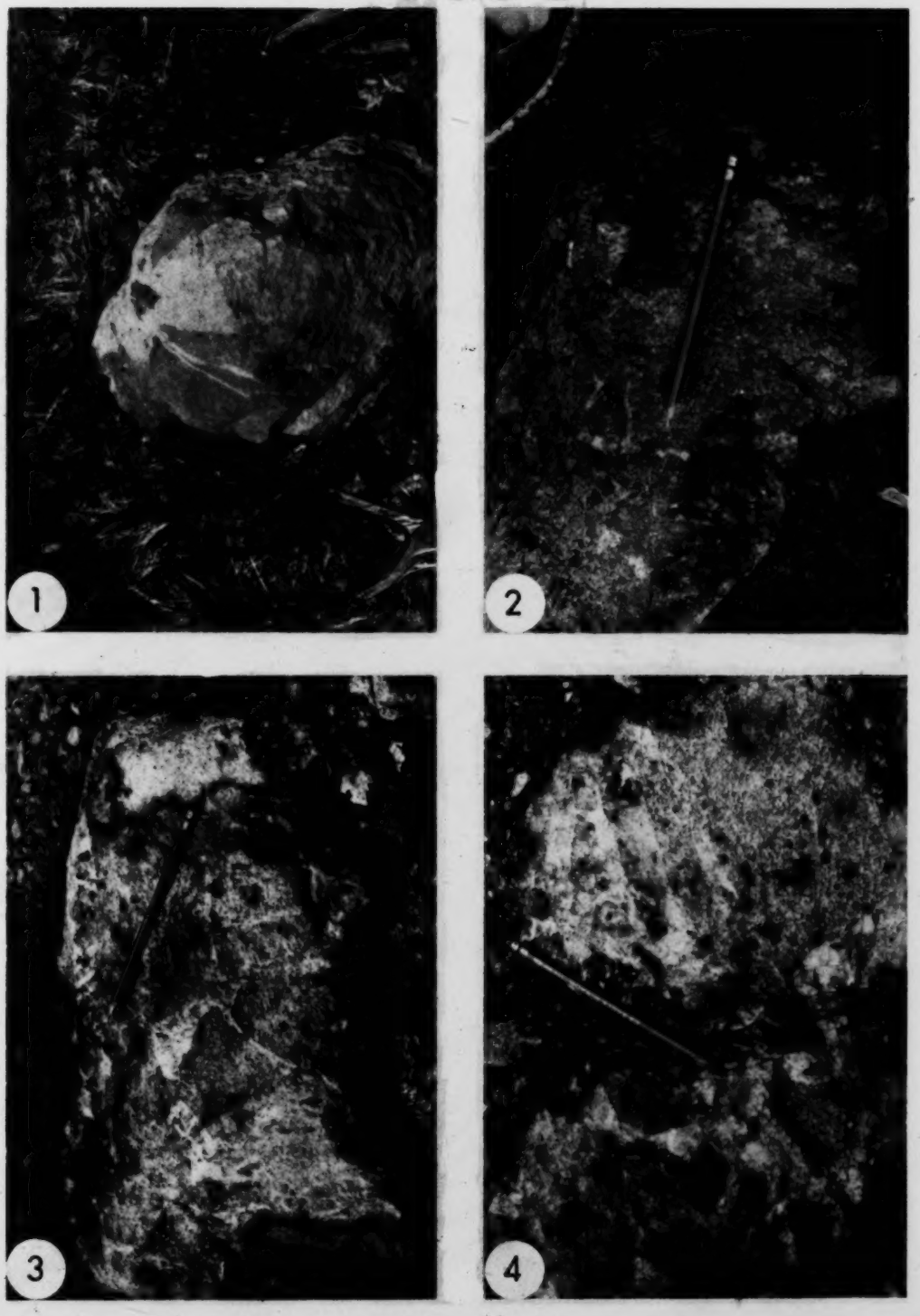


PLATE II

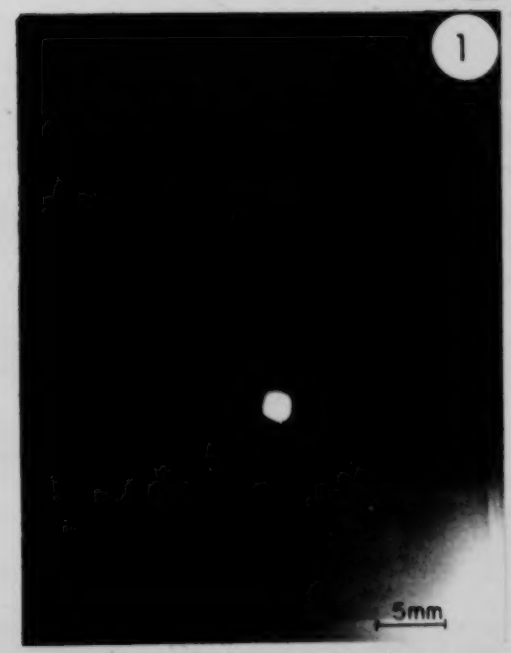
1. Radioluxograph of a polished section of brannerite from the "E" zone; (exposure time 8 hours). Traces of secondary U minerals are visible in the volume-expansion cracks emanating from the main crystal.

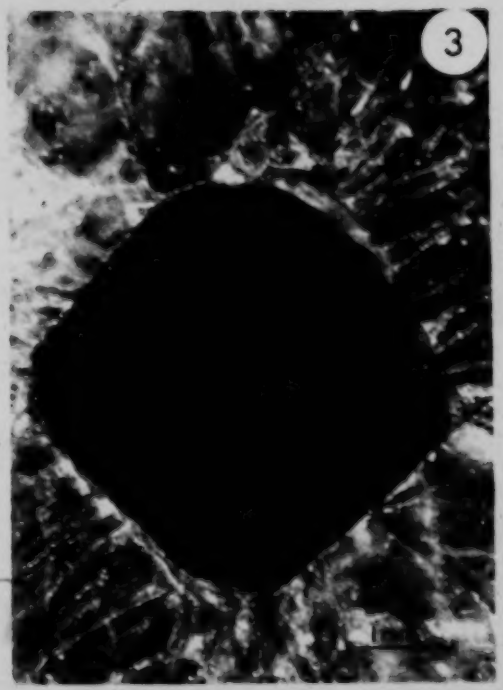
2. Photograph of the polished section in radioluxograph #1. The brannerite crystal lies in a quartz matrix with a portion of a quartz-sericite altered granodiorite fragment at the top of the polished section.

3. An enlargement of photograph #2. Note the volume expansion fracturing of the quartz host, and the microveinlets containing an unknown secondary uranium mineral cutting the brannerite crystal.

4. Reflected light photomicrograph of one corner of the above brannerite crystal showing development of secondary U minerals and their mobilization into fractures (plane light).

PLATE II.





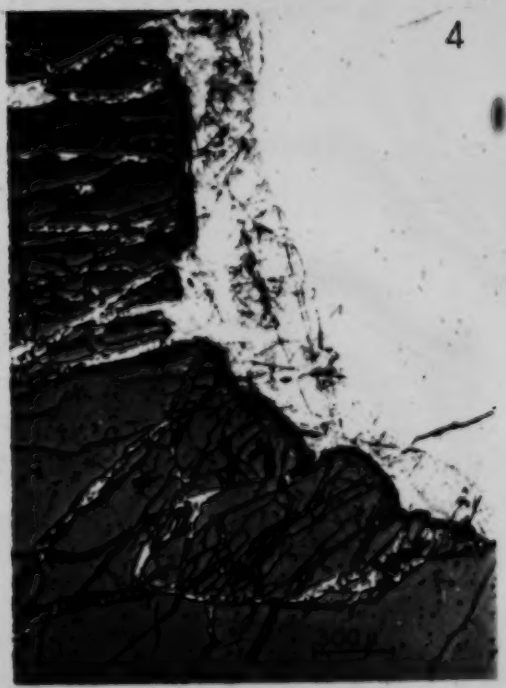


PLATE III

1. Photomicrograph of the development of amoeboid quartz in myrmekite from a granodiorite fragment in the "E" zone breccia (crossed nicols).

2. Photomicrograph of rod and dendritic quartz development in intumescent myrmekite in a Valhalla quartz monzonite fragment from the "E" zone (crossed nicols).

3. Photomicrograph of molybdenite lamellae associated with fluorite and muscovite from a granodiorite fragment in the "E" zone breccia (plane light).

4. Photomicrograph of the same specimen depicted in photograph #3 (crossed nicols).

PLATE III.

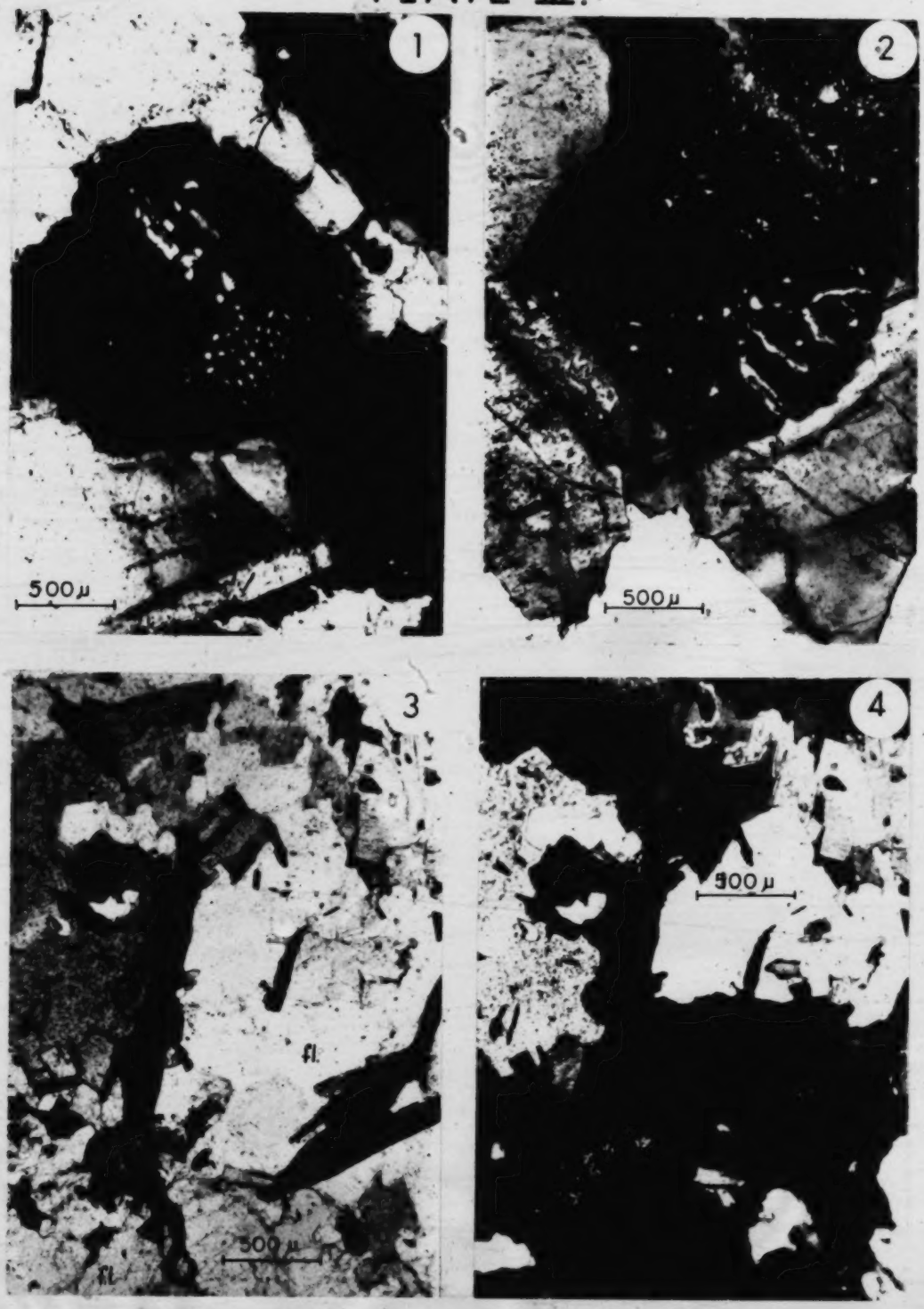


PLATE IV

1. Photomicrograph of palimpsest grains of biotite ("E" zone) mostly replaced by oxide minerals in a fragment of Nelson granodiorite (plane light).

2. Enlarged photomicrograph of the specimen shown in photograph #1 showing sericite between oxide lamellae. It appears that oxide development started in cleavage planes and spread laterally (crossed nicols).

3. Photomicrograph of the development of prehnite pods between the cleavage planes of biotite crystals. The example is from a granodiorite fragment in the "E" zone (crossed nicols).

4. Photomicrograph of the typical development of sericite along twin planes and cleavage of plagioclase grains in a quartz diorite fragment from the "E" zone breccia. Quartz-sericite alteration in this example is quite weak (crossed nicols).

PLATE IV.

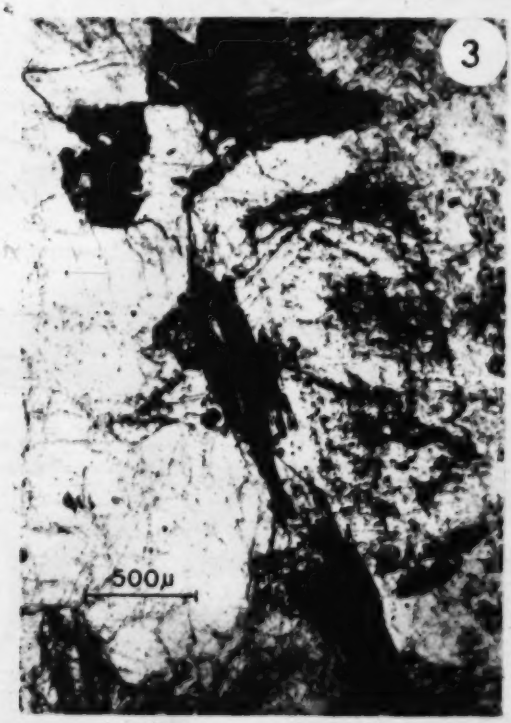


PLATE V

1. Photomicrograph of corroded quartz phenocryst from the "Lake" zone feldspar porphyry dike. Note the intruded lobes of a matrix composed predominantly of orthoclase and traces of carbonate (crossed nicols).

2. Photomicrograph of a corroded quartz phenocryst from the more hydrothermally altered north end of the "Lake" zone feldspar porphyry dike. The ground mass is potassic feldspar (altered) exhibiting a microcrystalline texture (plane polarized light).

3. Photomicrograph of intense quartz-sericite alteration in the "E" zone. Plagioclase has been destroyed and corroded muscovite has developed (crossed nicols).

4. Photomicrograph of intense quartz-sericite alteration with partial development of new un-altered microcline. Note the spotty appearance of recrystallized quartz grains formed from the breakdown of plagioclase (crossed nicols).

PLATE V.

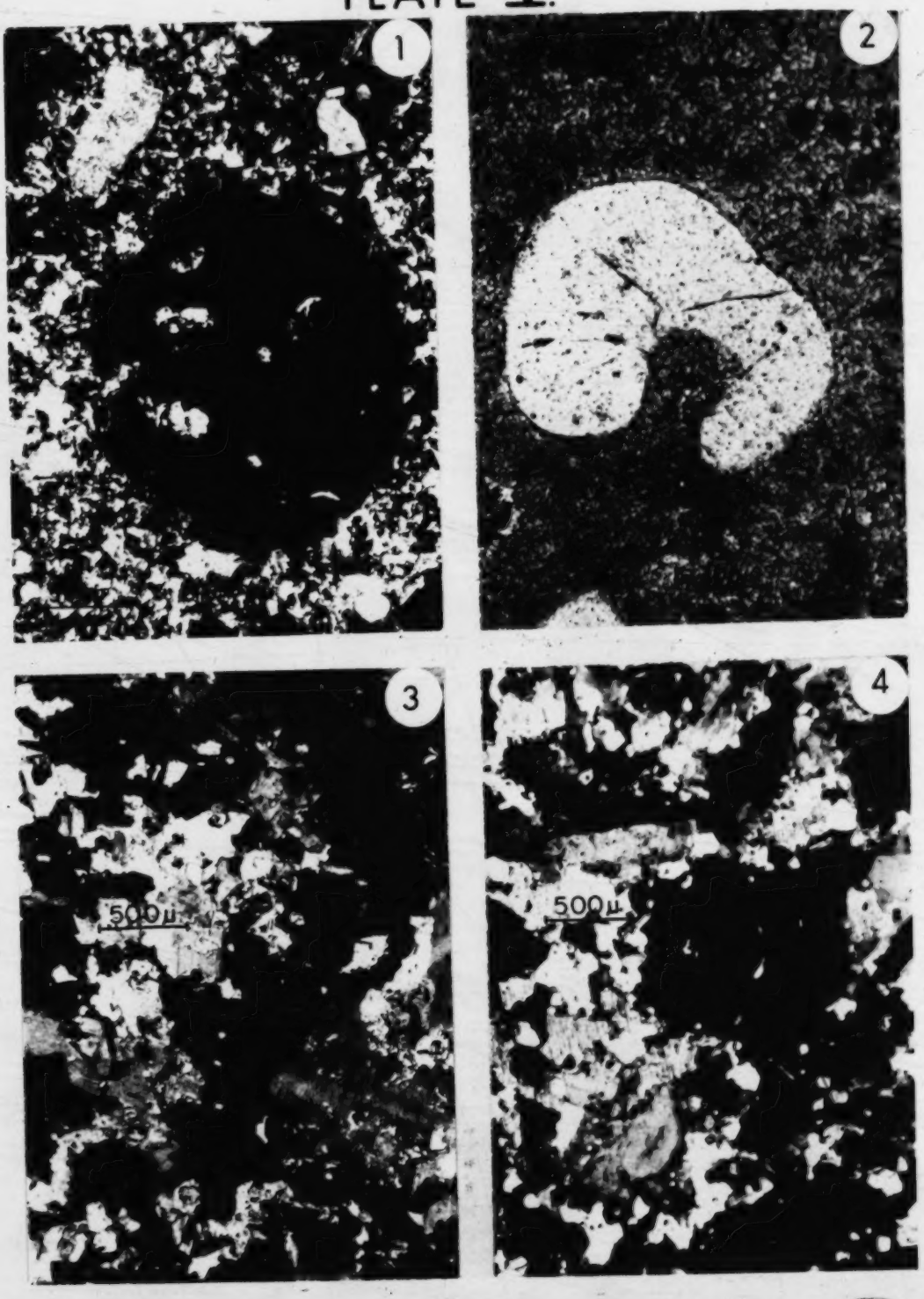


PLATE VI

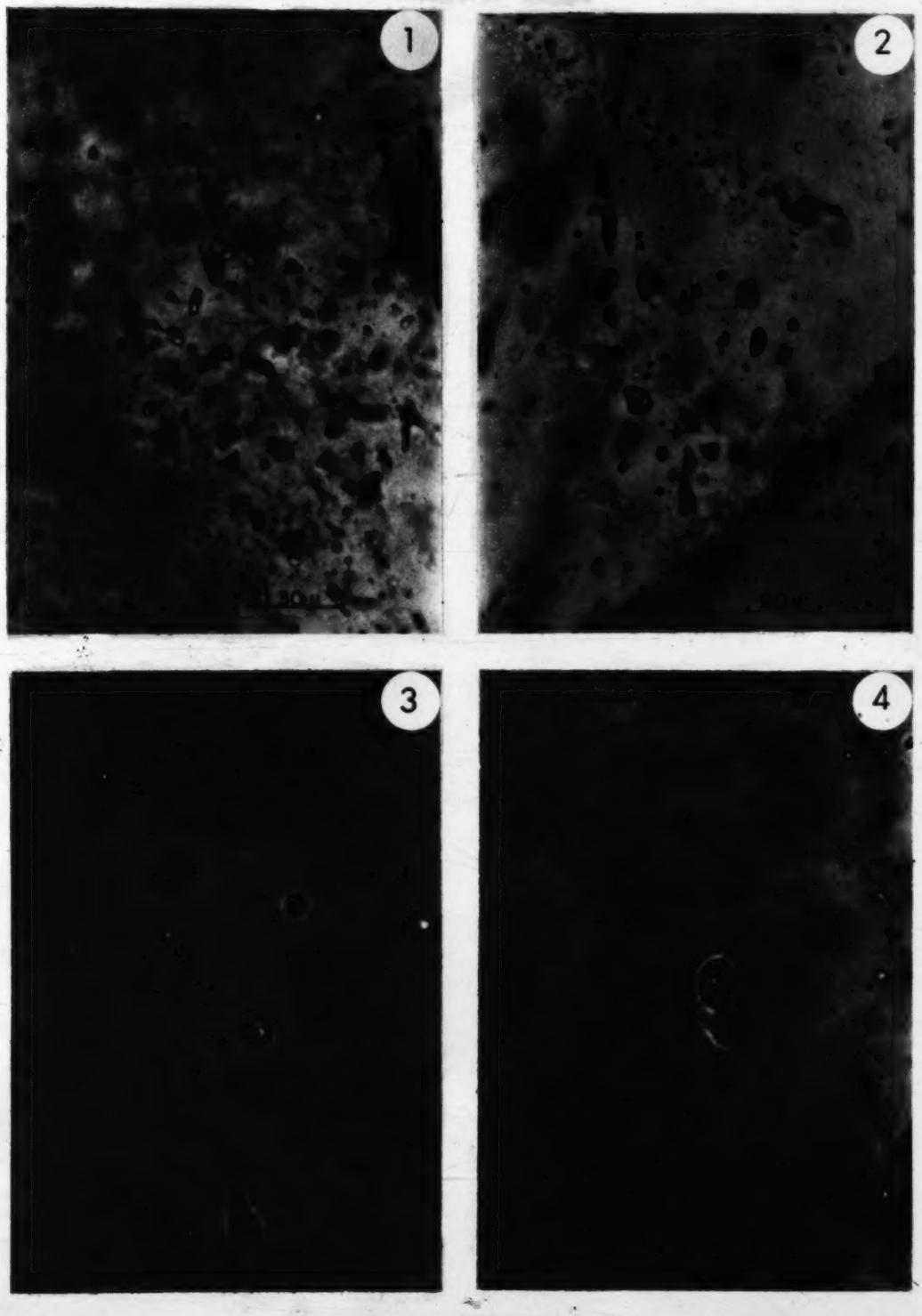
1. Photomicrograph of primary fluid inclusions from the quartz cement of the "E" zone. Note their variability in that some inclusions are empty whilst others contain CO_2 gas or liquid.

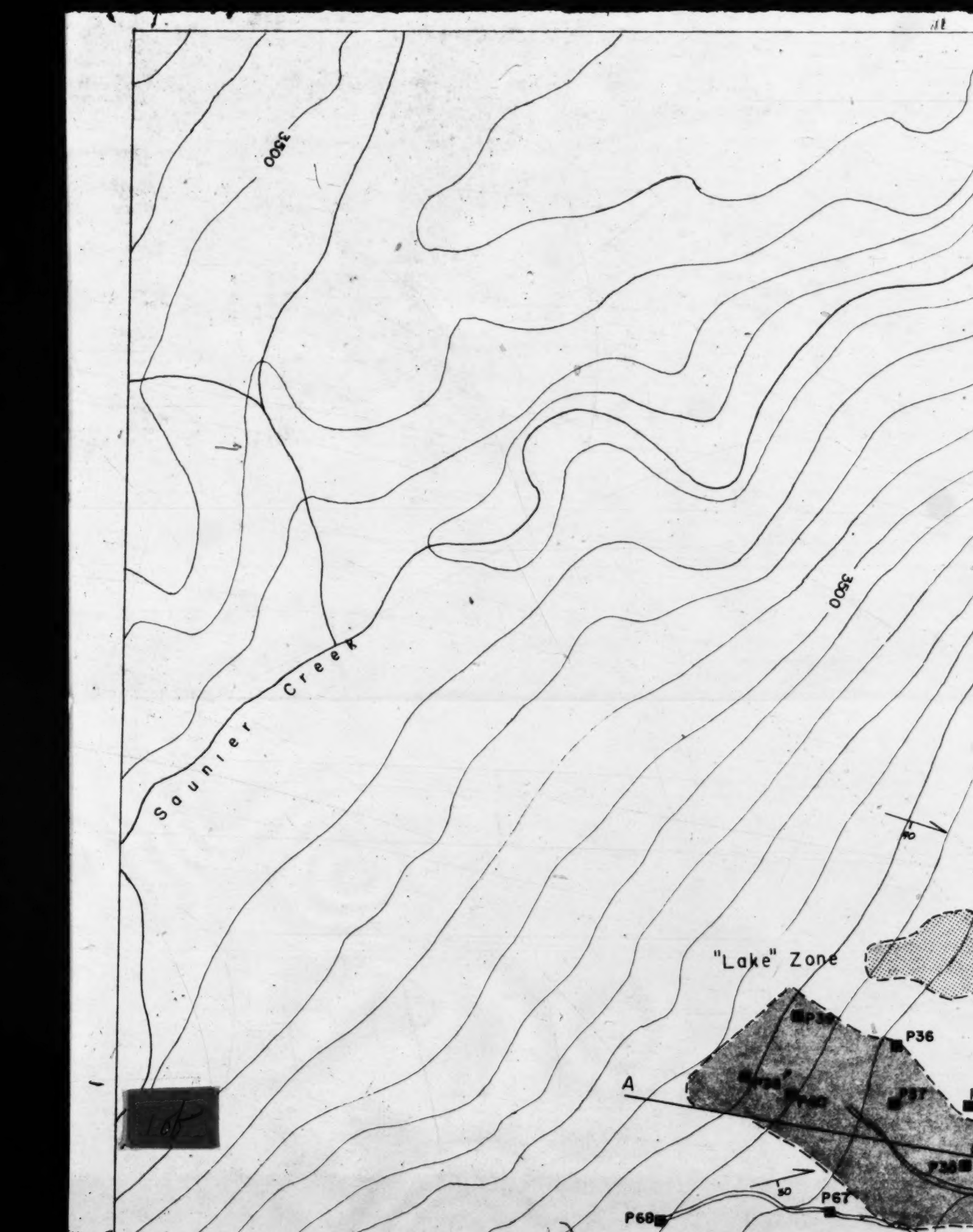
2. Photomicrograph of both primary and aligned, smaller, secondary fluid inclusions from the quartz cement of the "E" zone. The larger non-aligned primary inclusions show CO_2 bubbles with a variance in bubble volume to chamber volume.

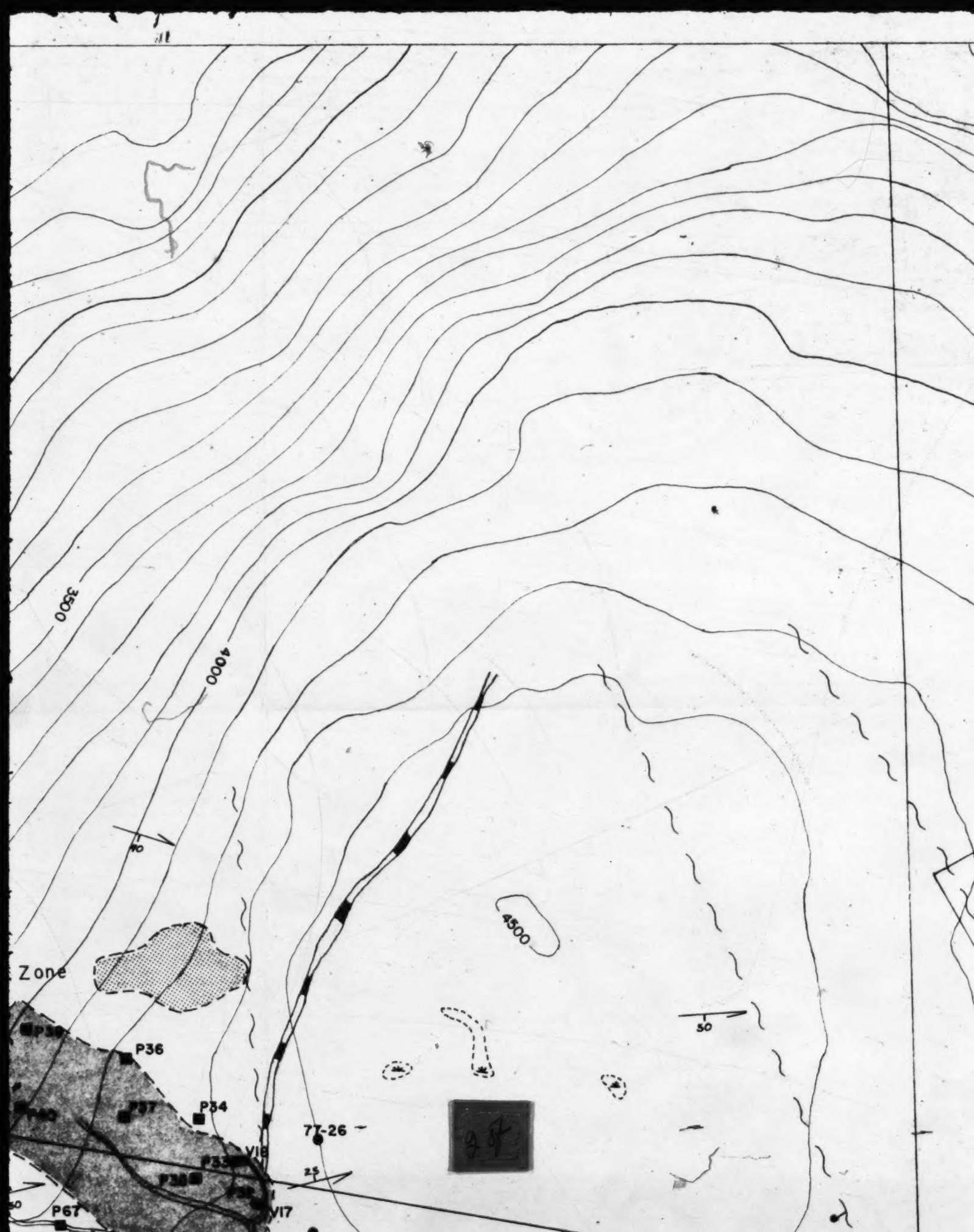
3. Photomicrograph of fluid inclusion with CO_2 gas, liquid CO_2 and an aqueous phase. The specimen is from the quartz matrix of the "E" zone.

4. Photomicrograph of a fluid inclusion showing the same 3 phase situation as depicted in photograph #3. Again from the "E" zone breccia cement.

PLATE VI.




3500
3500
Saunier Creek
"Lake" Zone
P36
A
P67
P68
50
50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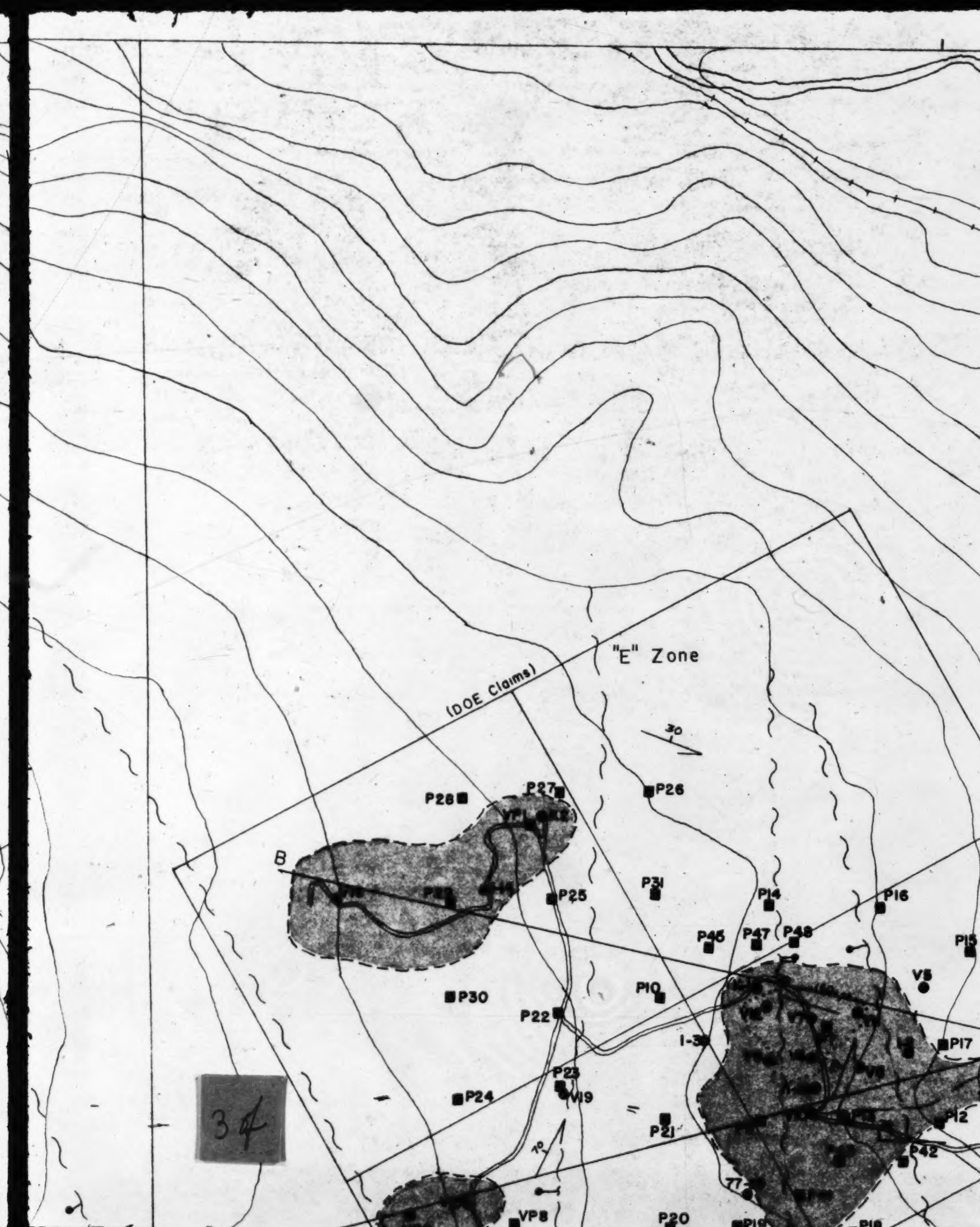
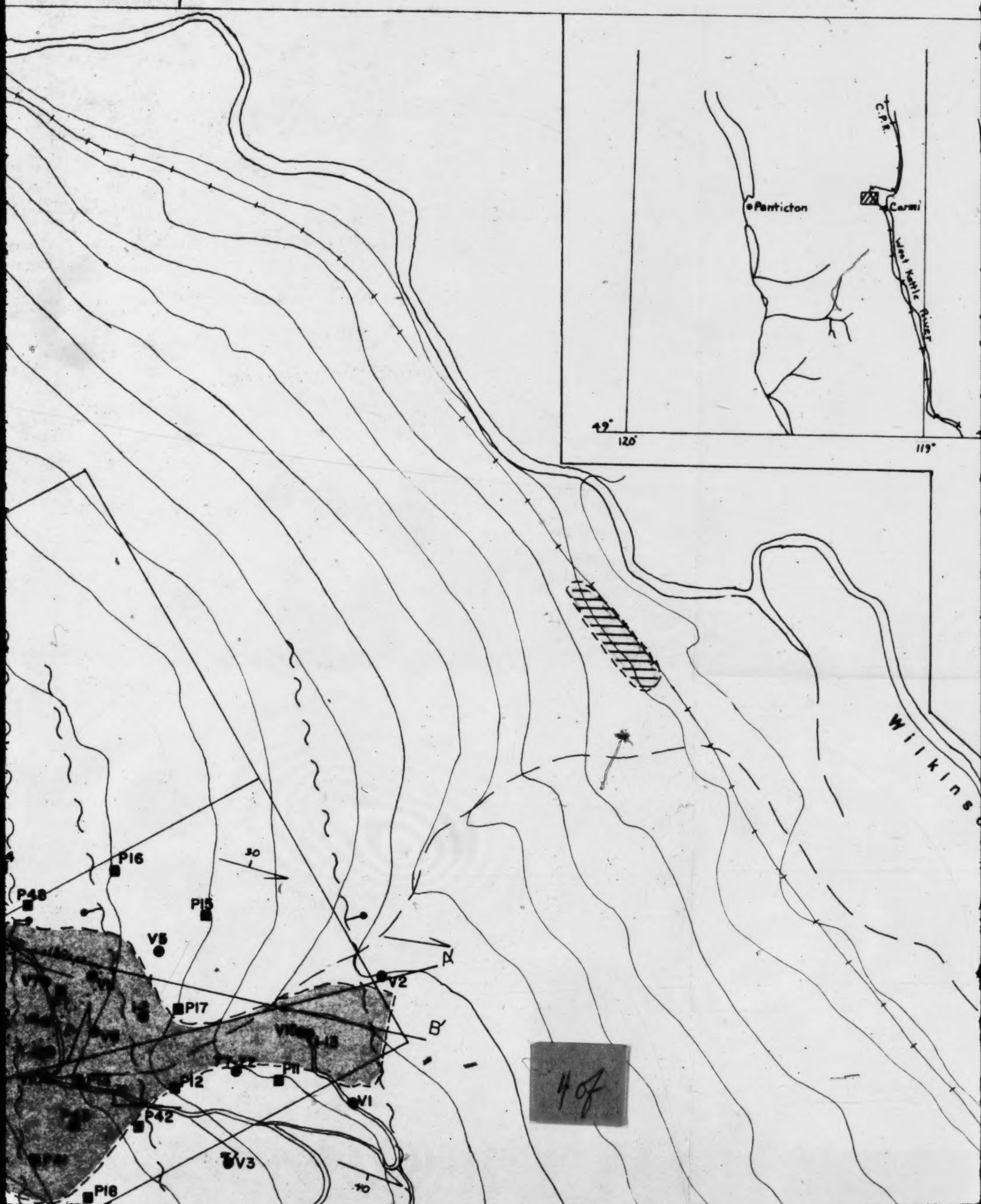
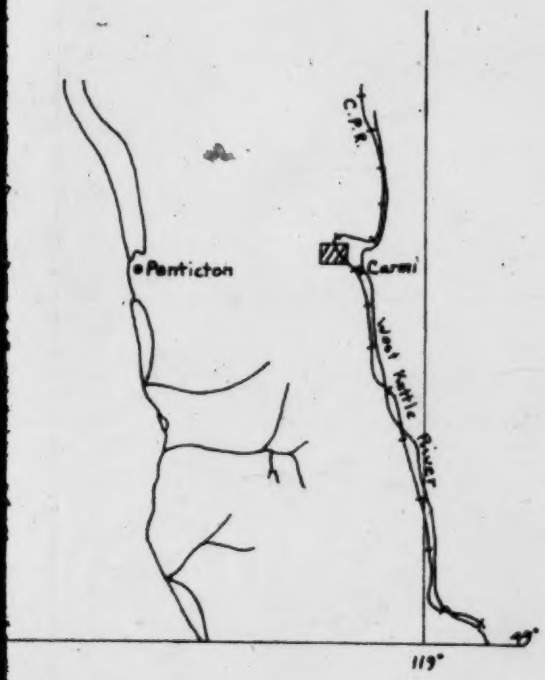
4000
4500
Zone
P36
P34
77-26
V18
V17
P67
50
25


"E" Zone
(DOE Claims)
B
P28
P27
P26
P31
P25
P14
P16
P46
P47
P48
P15
V5
P10
P30
P22
I-3
P17
P23
V19
P24
P21
P12
P42
VP8
P20
34


Penticton
Carmi
C.P.R.
West Kettle River
49°
120°
119°
Wilkinson
P16
P48
P15
V5
V2
P17
V1
P12
P11
P42
V3
P18
30
A
B
4 of

CARMI B.C. GEOLOGICAL MAP



LEGEND

- Nelson granodiorite
- Nelson quartz monzonite
- Breccia
- blind breccia
- Valhalla quartz monzonite (not exposed)
- Feldspar porphyry
- Anarchist Group

SYMBOLS

- Fault (assumed) with downthrown side
- Foliation (inclined, vertical, horizontal)
- Joint
- Geological boundary (defined, assumed)
- Radioactive anomaly (outline)

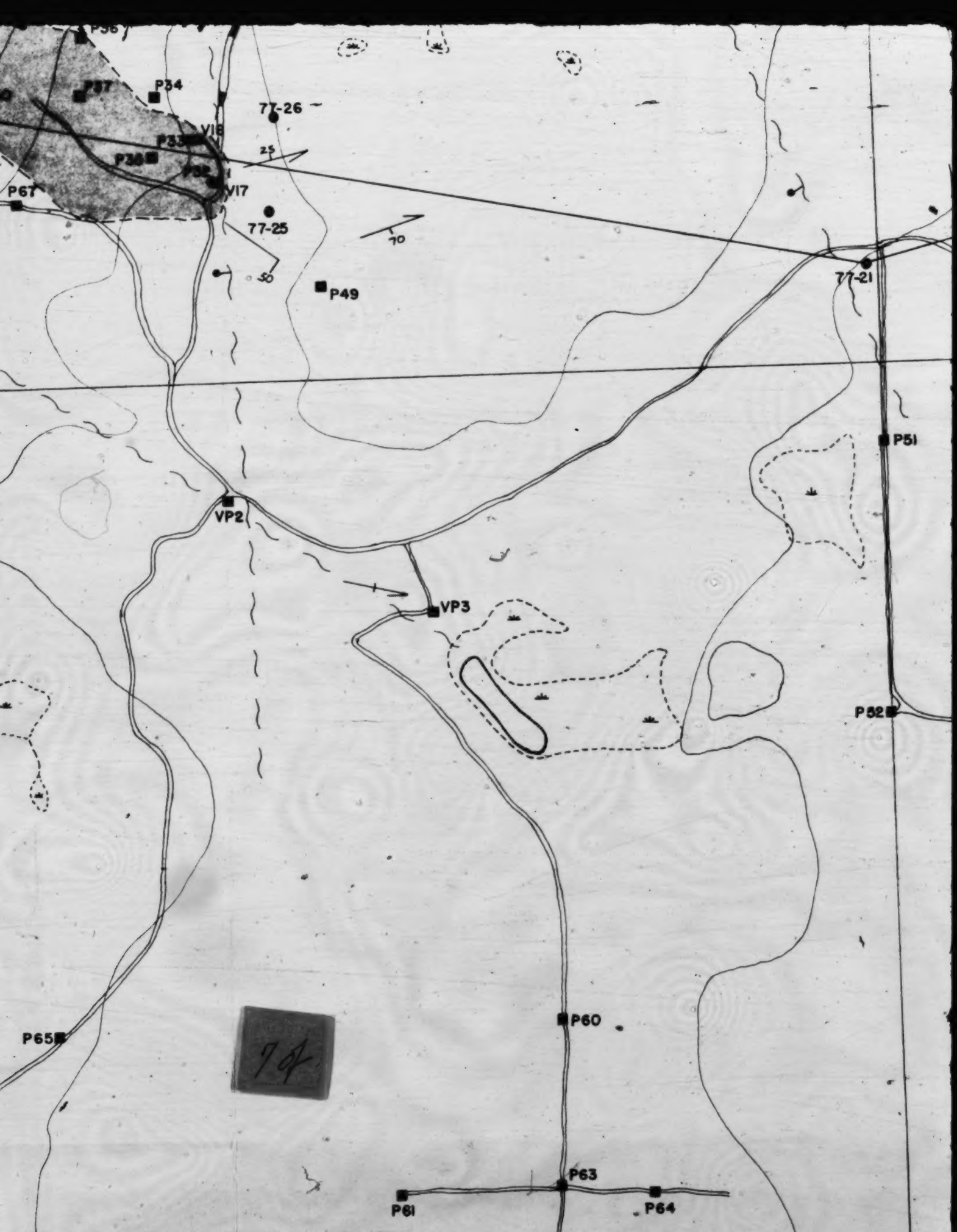
0 200 400 800 feet

Wilkinson Creek

N

J.M.K. Oct. '77

A
P38
P37
P36
30
P67
P68
Base line 10000
P65
P66
64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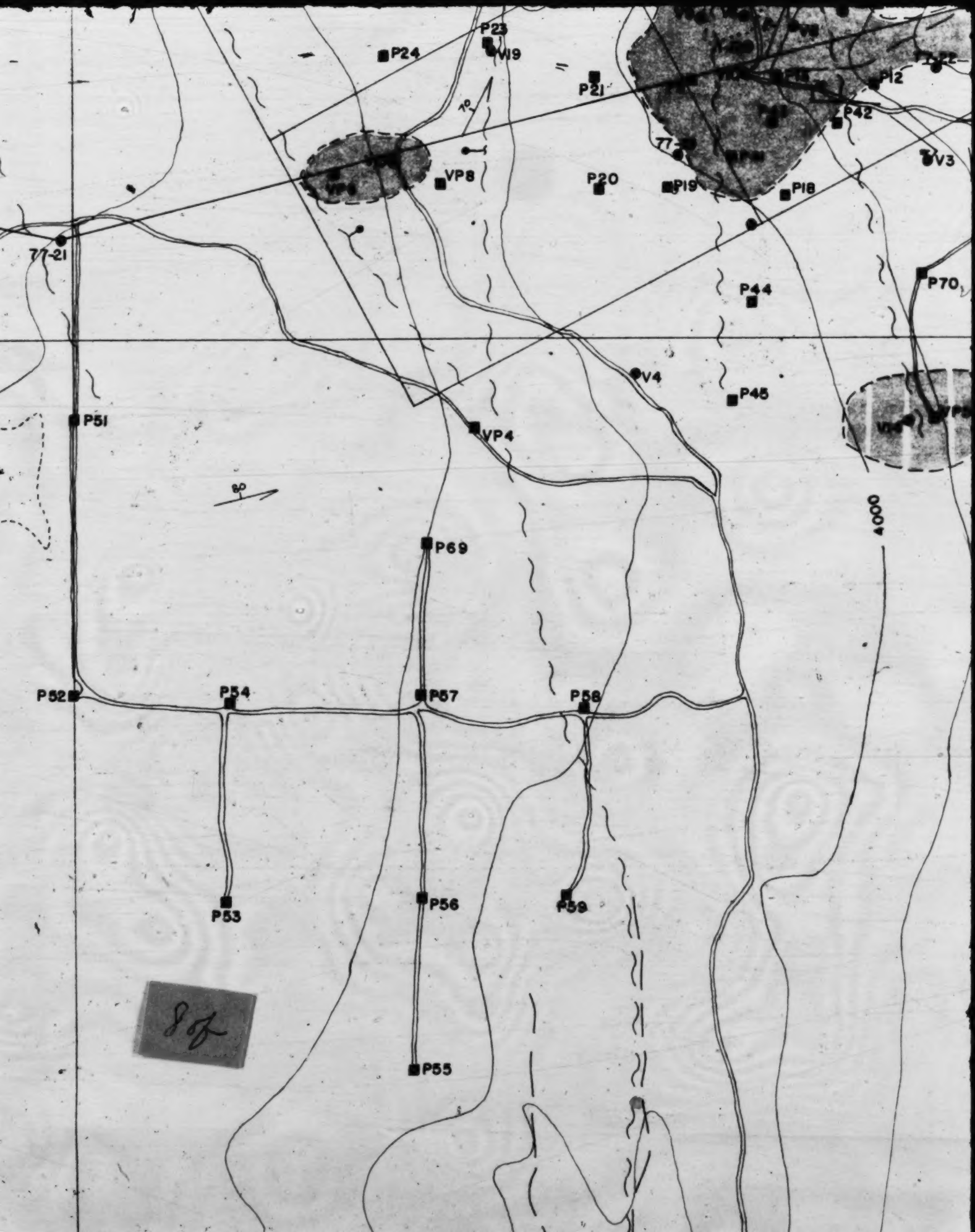
77-26
V18
P33
25
P38
P32
P67
V17
77-25
10
50
P49
77-21
P51
VP2
VP3
P52
P65
P60
P63
P61
P64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P24
VI9
P21
P12
P42
V3
VP8
P20
P19
P18
77-21
P44
P70
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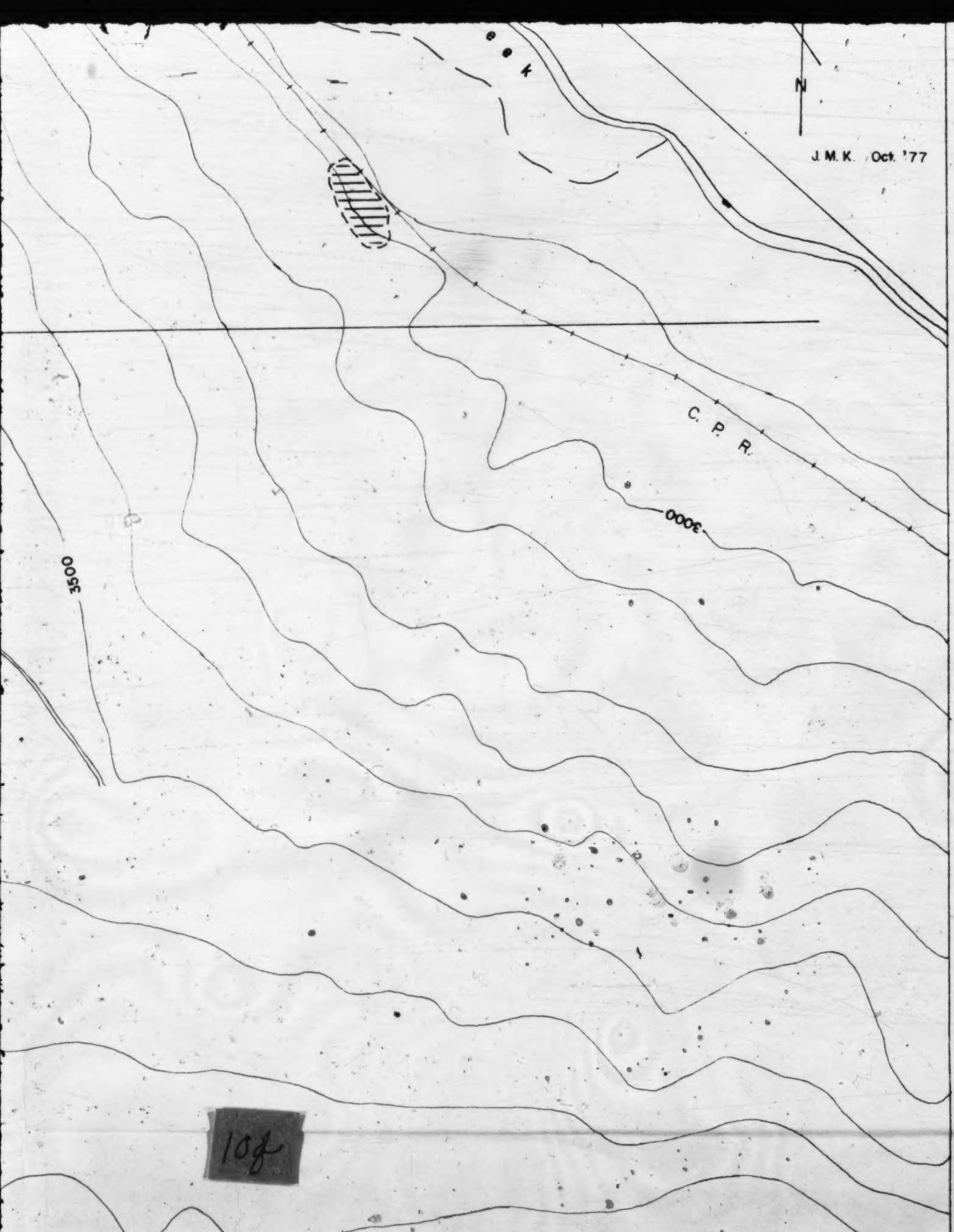
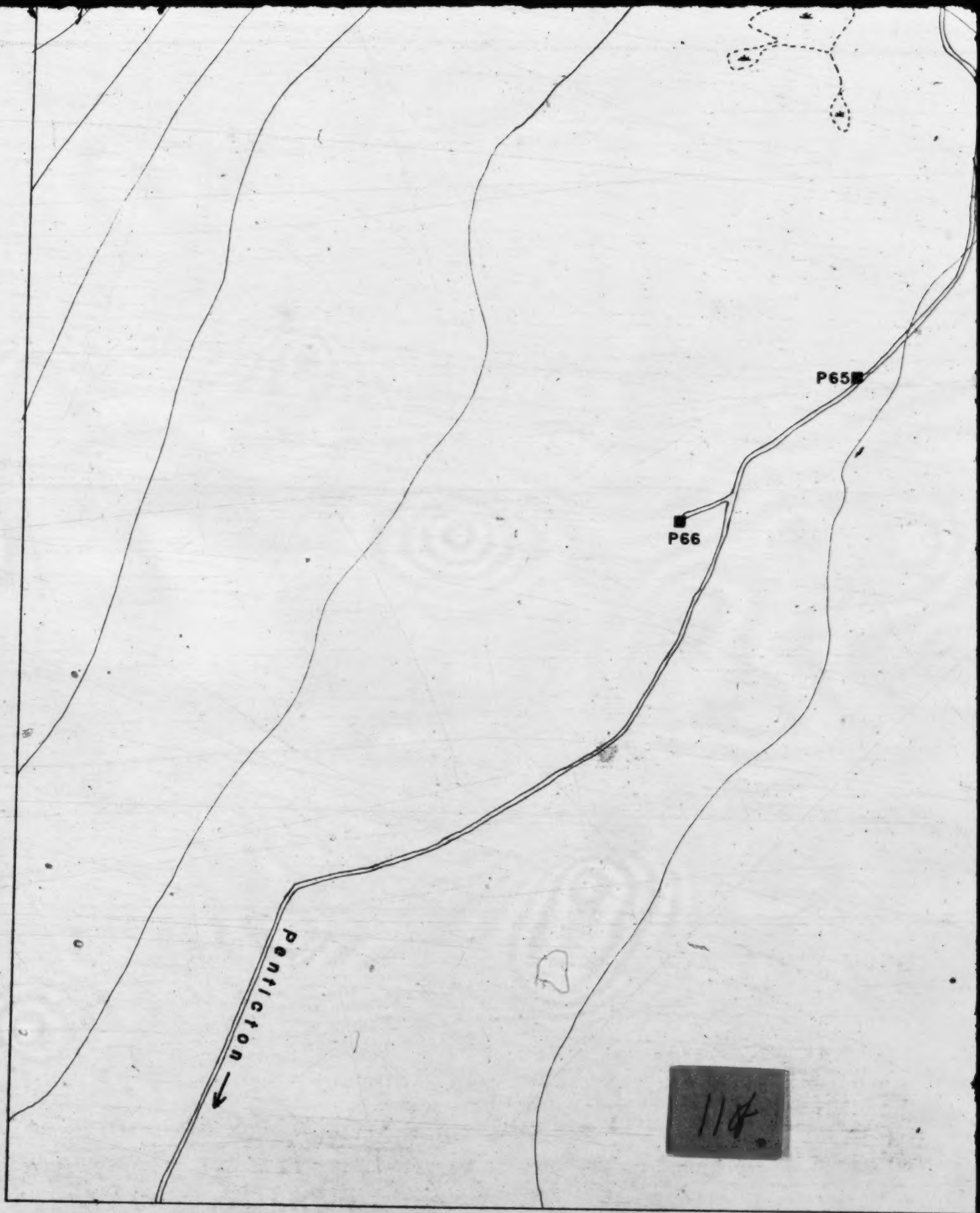
P45
P51
VP4
P69
4000
P52
P54
P57
P58
P53
P56
P59
P55

B'
P12
P11
P42
V1
V3
P18
P70
P44
P71
P45
P72
4000
3500


N
J.M.K. Oct. '77
C. P. R.
3000
3500
108



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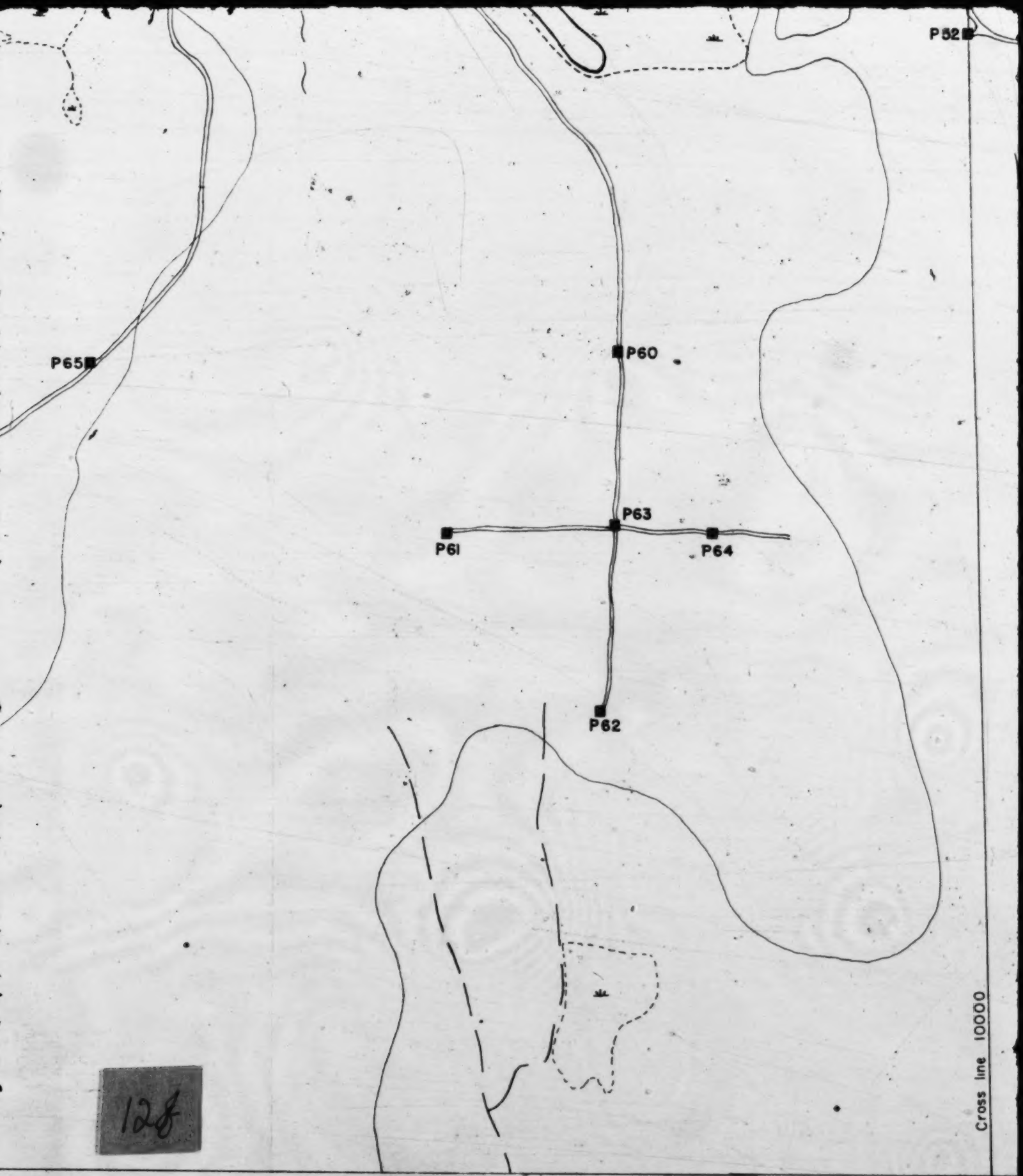

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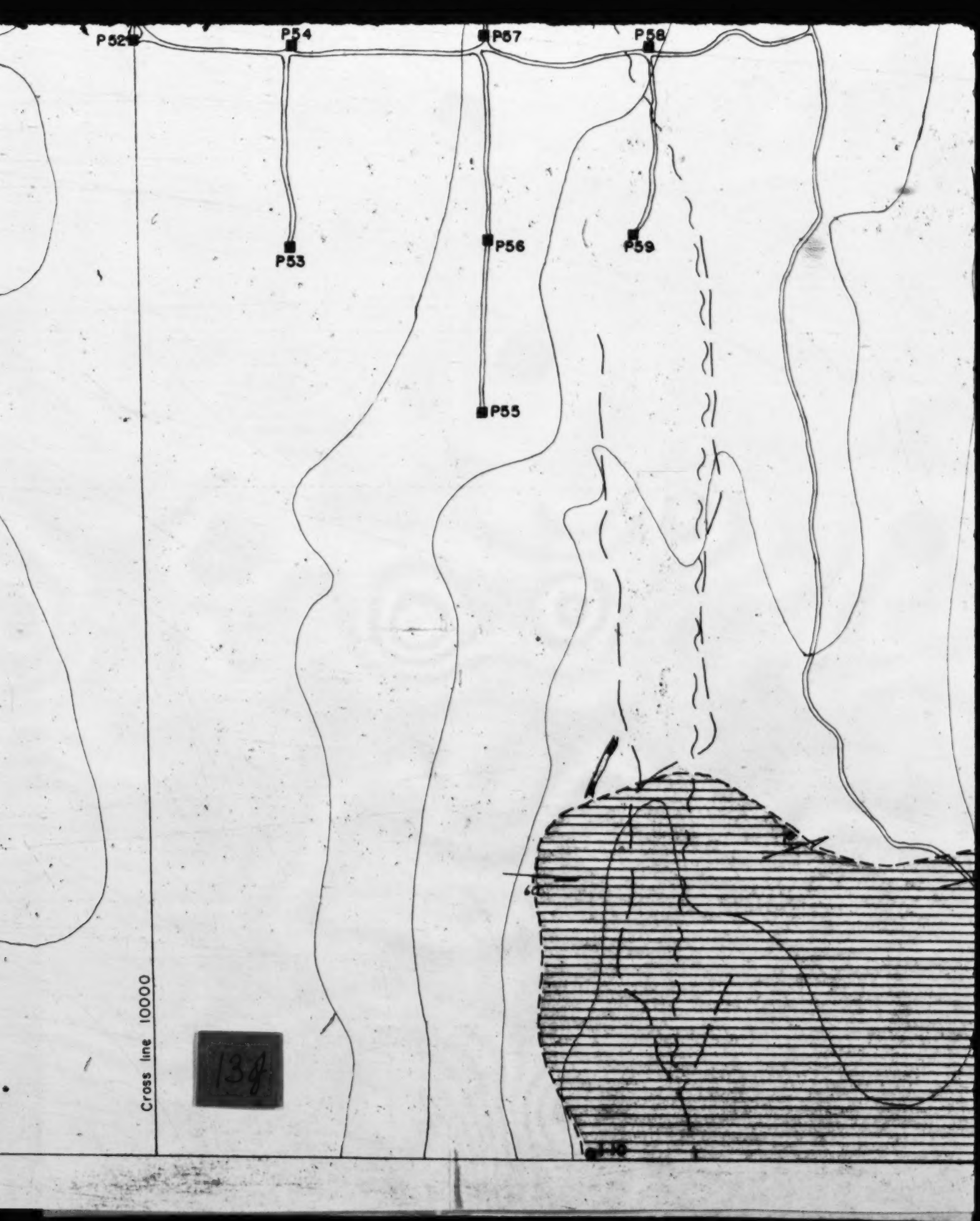

P52
P54
P57
P58
P53
P56
P59
P55
P60
Cross line 10000
134

148

MAP 7.

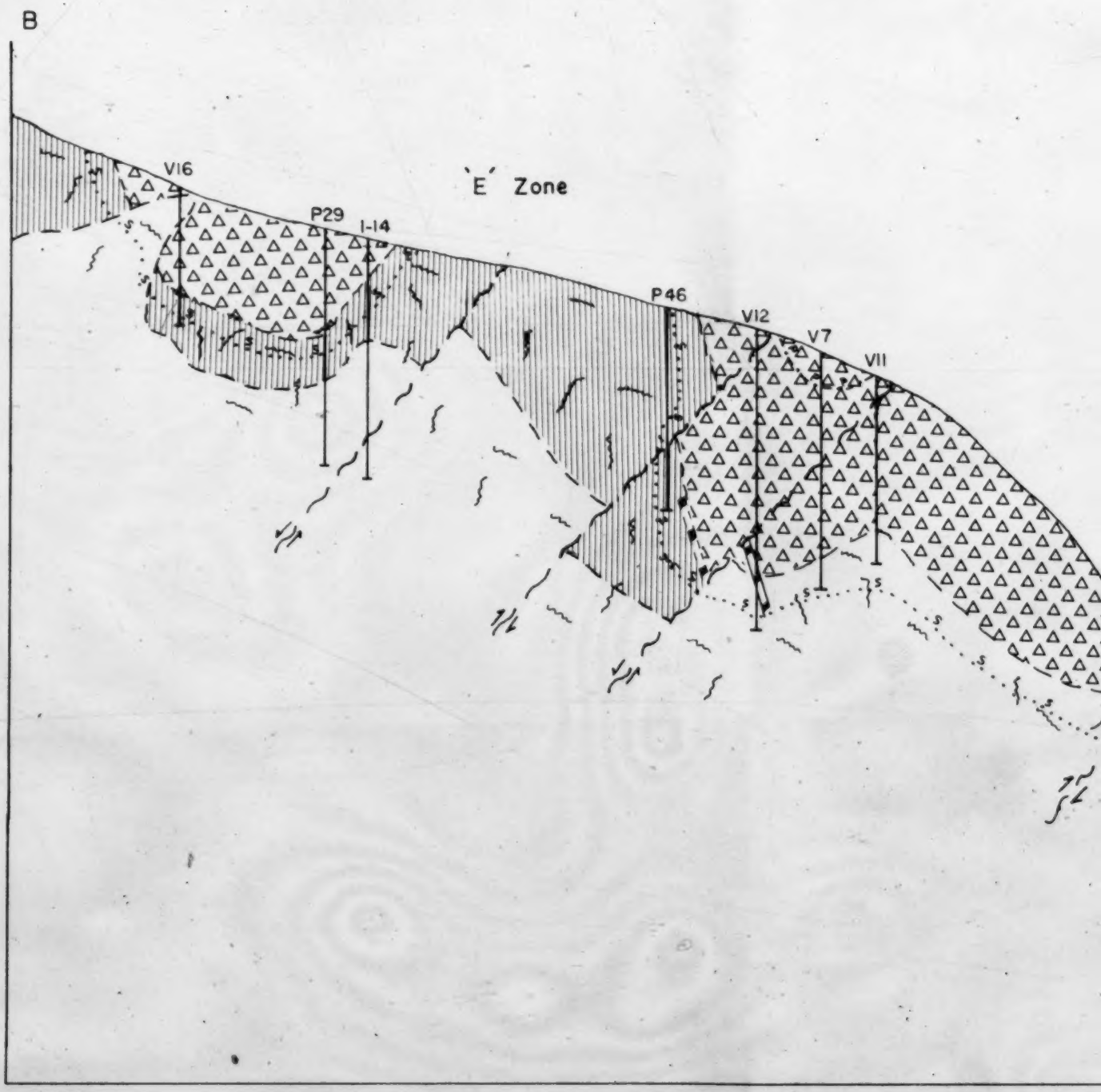
DRILL HOLE LOCATIONS

KENNCO LTD. – K2 (1965)
I.M.C. LTD. – I-4 (1970)
VESTOR LTD. – V10 (1974, 1976) VP3 (1974)
GRANBY LTD. – P9 to P49 (1975)
CRAIGMONT LTD. – P51 to P72 (1976), 77-21 (1977)

● DIAMOND DRILL HOLE

■ PERCUSSION DRILL HOLE

15 of 15

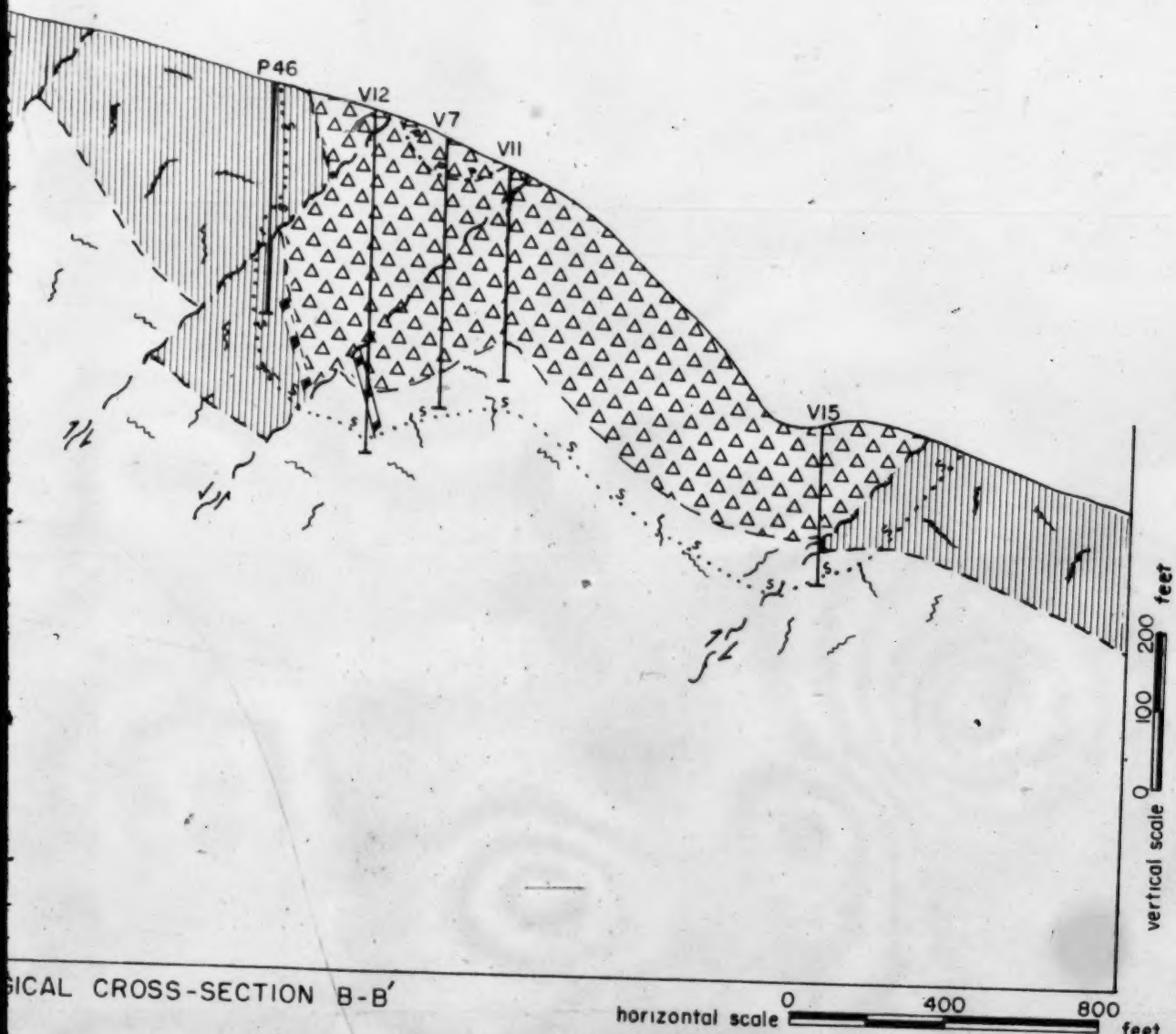


CARMI B.C. GEOLOGICAL CROSS-SECTION B-B'

horizontal s

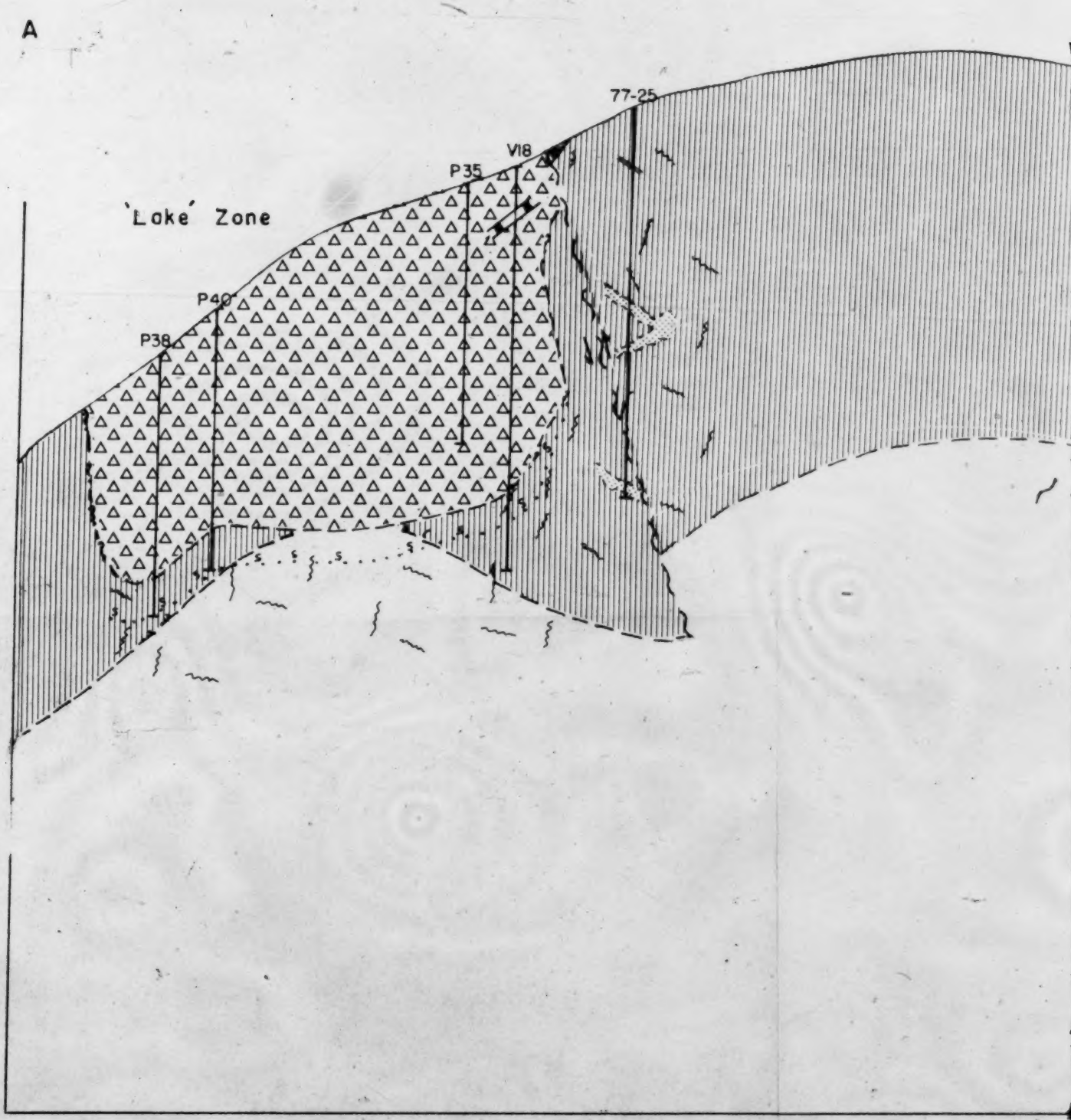
B′

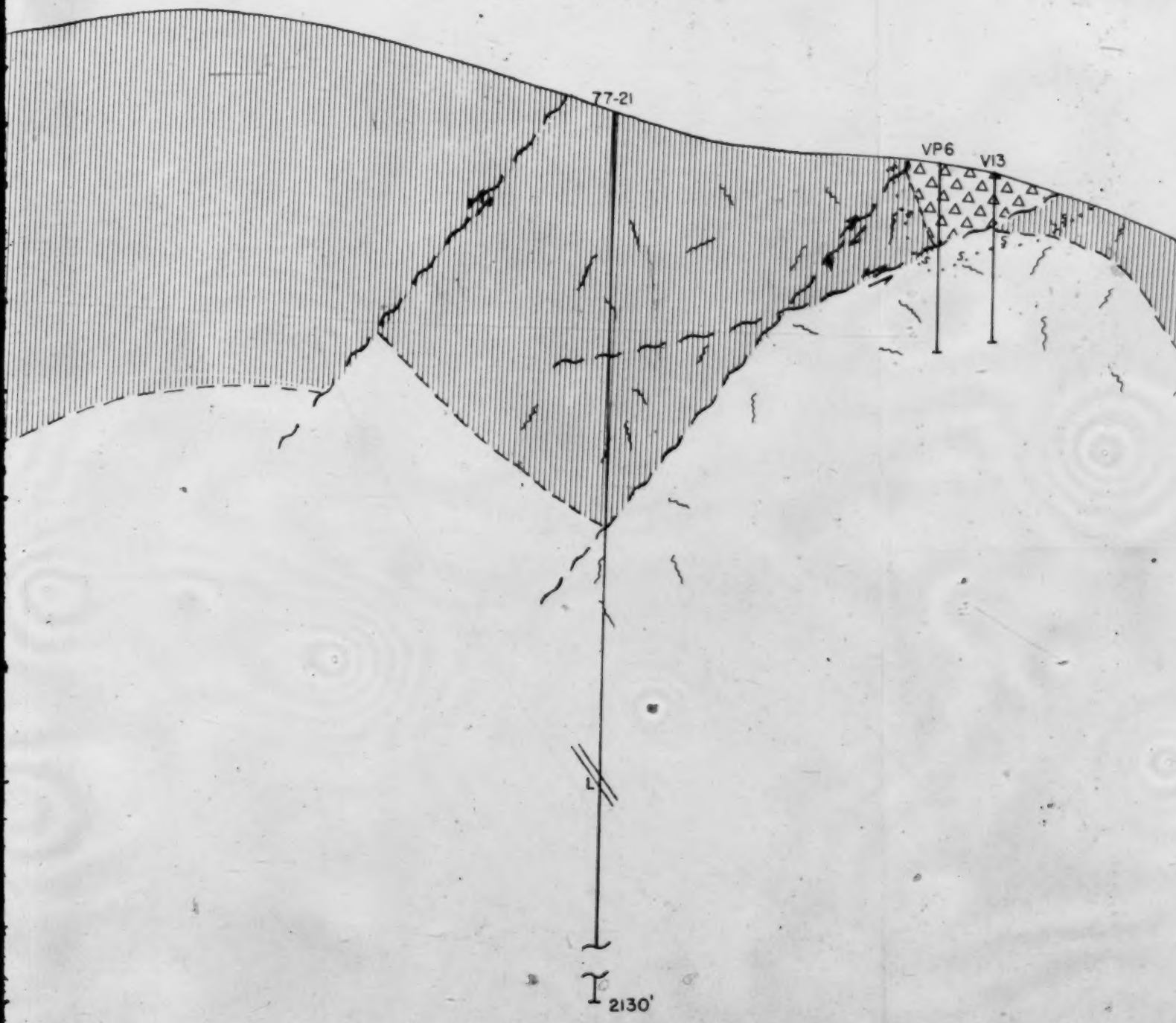
'E' Zone



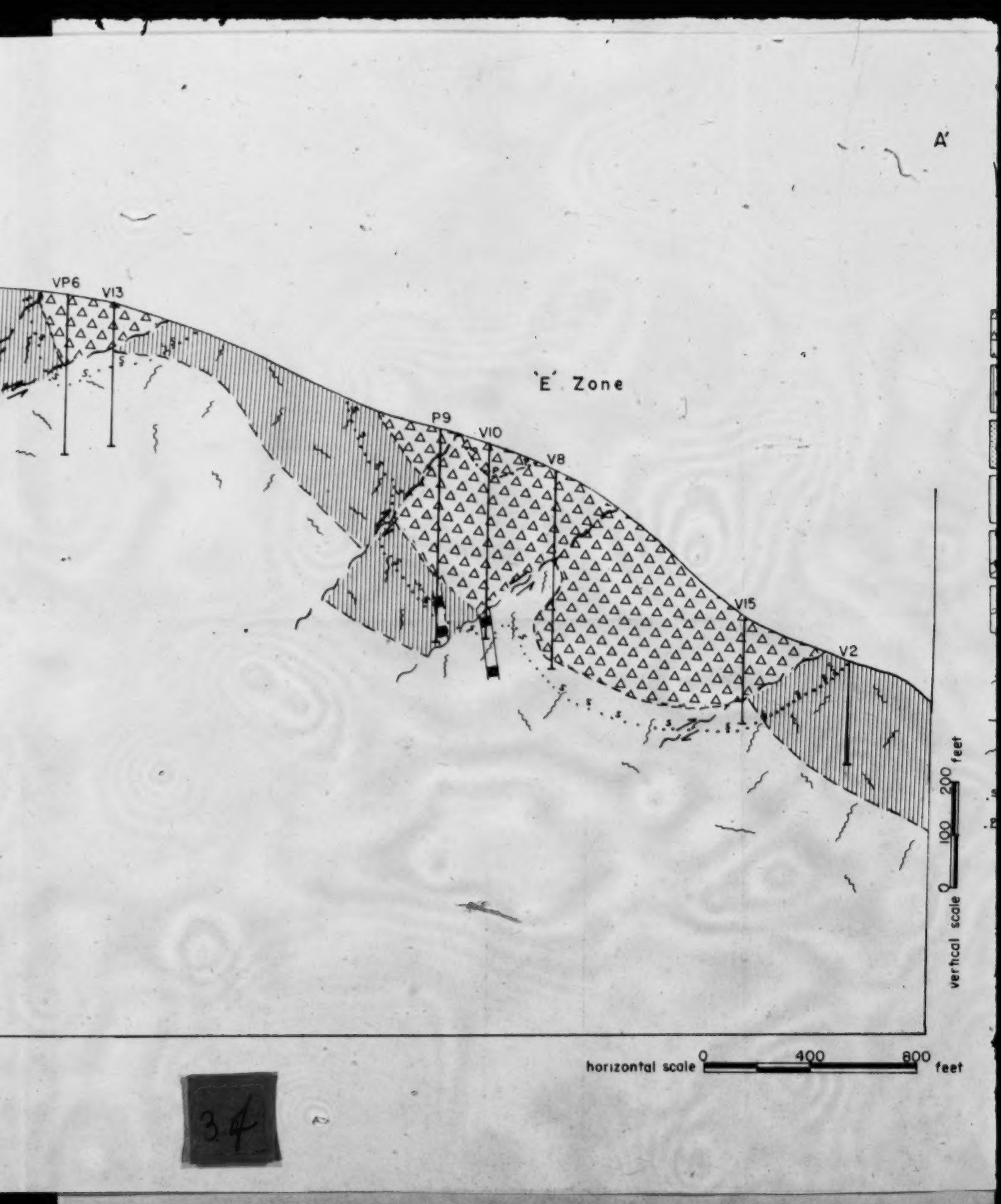
GICAL CROSS-SECTION B-B′

242

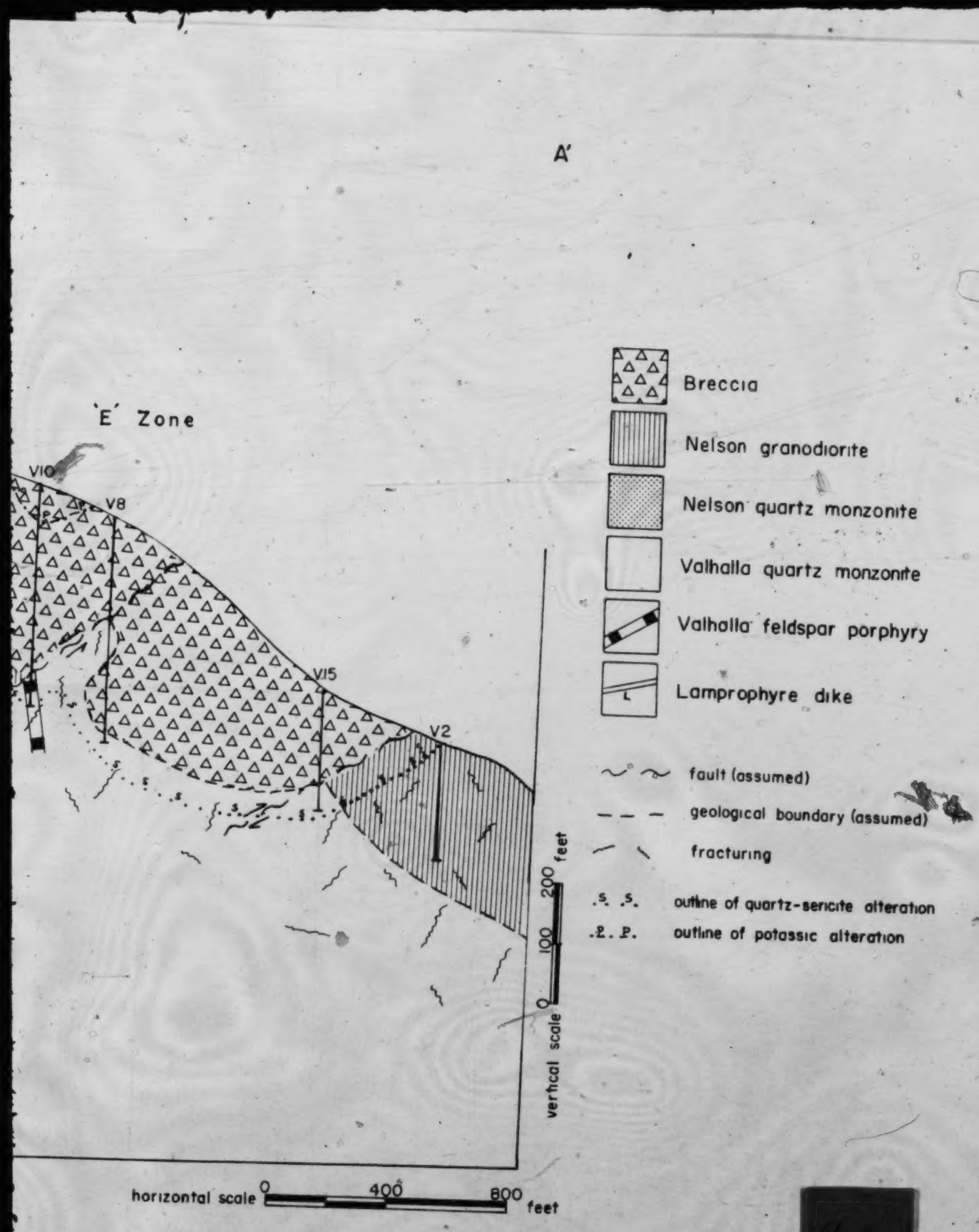

A
77-25
V18
P35
'Lake' Zone
P40
P38
CARMI B.C



CARMI B.C. GEOLOGICAL CROSS-SECTION, A-A'


A'
VP6
V13
'E' Zone
P9
V10
V8
V15
V2
vertical scale
0
100
200
feet
horizontal scale
0
400
800
feet

3.4


A'
'E' Zone
V10
V8
V15
V2
Breccia
Nelson granodiorite
Nelson quartz monzonite
Valhalla quartz monzonite
Valhalla feldspar porphyry
Lamprophyre dike
L
fault (assumed)
geological boundary (assumed)
fracturing
.S. .S. outline of quartz-sericite alteration
.P. .P. outline of potassic alteration
0
100
200
feet
vertical scale
horizontal scale
0
400
800
feet